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DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

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January, 1948

Photo by Laurence Lowry

Edgar Station of Boston Edison Company in which will be installed a 585,000-lb per hr steam generating unit of 1600 psi pressure and 1000 F total steam temperature, with reheat

Burning Bagasse at Cuban Sugar Centrals ▶

Behavior of Ash in Pulverized Coal Furnaces ▶

Instruments and Combustion Control for Small Plants ▶

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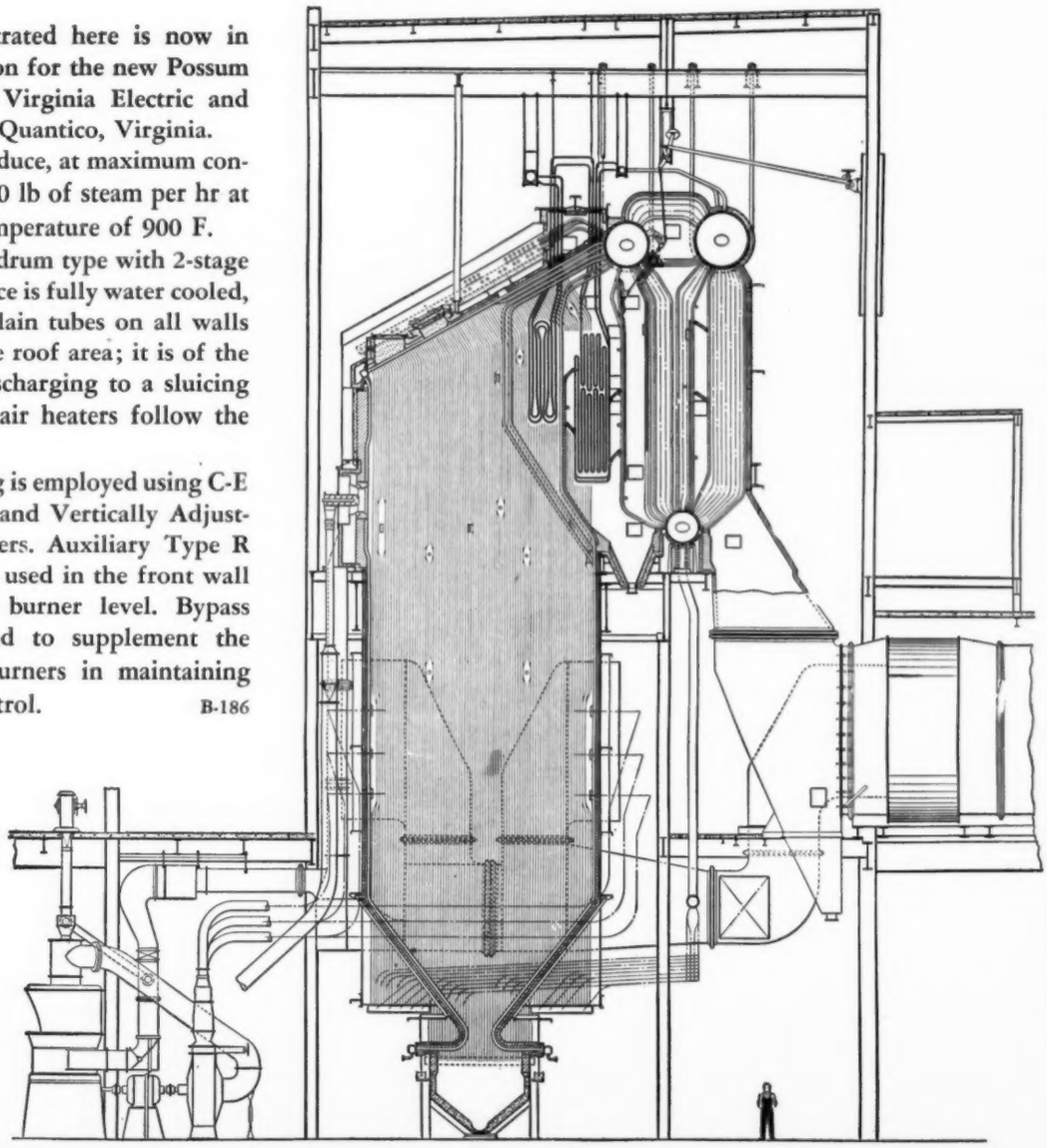

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COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

VOLUME NINETEEN NUMBER SEVEN

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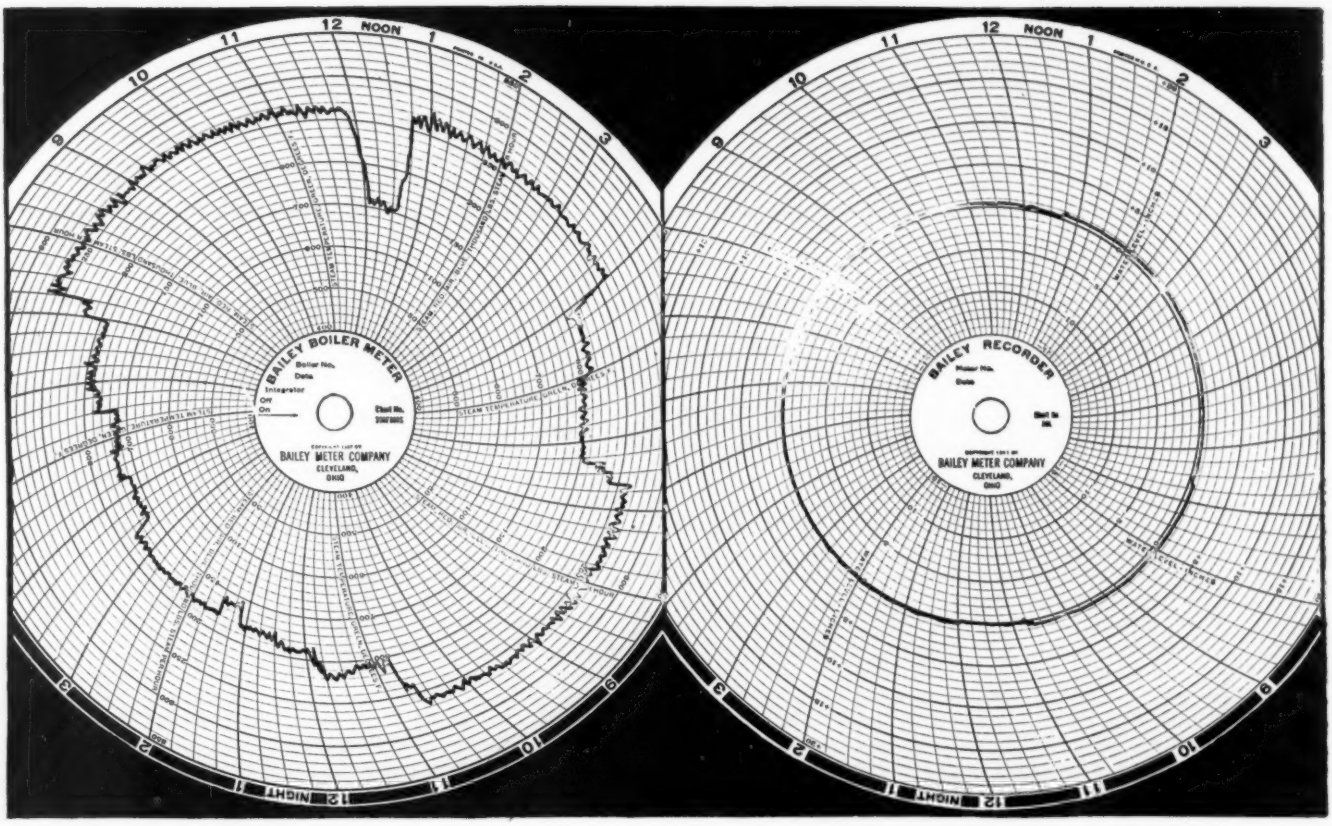

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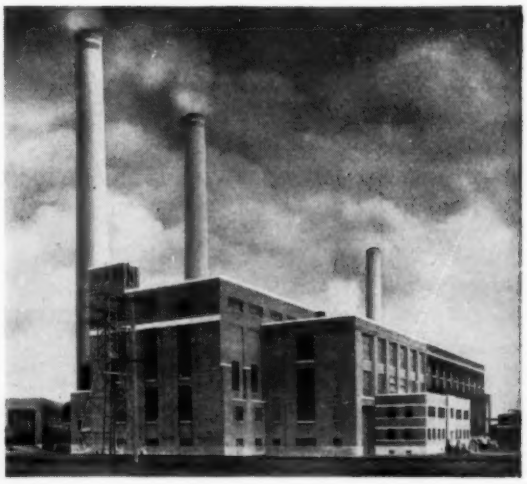

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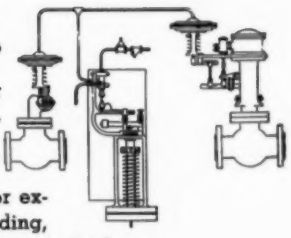

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EDITORIAL

Combustion Engineering Courses

The place of fuels in our economic structure is now being recognized, and technological advances in their production and utilization are assuming ever-increasing importance, as is attested by the large amount of research being conducted in this field. The subject is a broad one, involving supply, production and application of different fuels in which their combustion plays a major rôle. Neither rule-of-thumb methods nor the theoretical approach provide the answer to the efficient burning of fuels; instead it represents a combination of theory, research and empirical design based on experience and tests—in other words, an engineering approach. This is especially important now that lower grade coals have so largely replaced premium grades; also because we appear to be approaching an era of synthetic liquid fuels to augment the supply from natural sources.

It is a subject that warrants greater attention than customarily accorded by engineering schools. Although one university has lately initiated a course in combustion engineering and several others are understood to be giving the idea serious consideration, it has wide possibilities, especially in view of the large amount of material that has been made available. In those schools whose mechanical engineering curriculum extends over five years such a course might well be made an adjunct to Heat Power Engineering, whereas in others in might form part of an elective in Fuels Technology, or be handled as a part of graduate work.

The coal industry, through the National Coal Association, has already initiated a program to stimulate interest among engineering students in colleges having mining courses, by having a representative visit them and point out that coal is basic to all industry and that wide opportunities are offered the graduate through knowledge of its production and efficient utilization.

While the general trend in engineering education is away from specialization, there are certain subjects whose importance these days warrants more than passing attention. Conservation of fuels, through proper combustion, is one of these. Opportunities for graduates with this background are numerous and include employment by large coal and oil companies, certain industrial research laboratories, central stations and manufacturers of steam generating and fuel burning equipment in both the industrial and residential fields.

Steam Generator Progress and Trends

At the Panel Discussion held during the A.S.M.E. Annual Meeting in Atlantic City last month it was apparent that a greater degree of standardization of steam generating equipment would be welcomed by both customers and manufacturers as one means of holding down initial costs—that is to say, engineering costs, inasmuch as material and fabricating costs are largely beyond the control of the designer. However, this commands the close cooperation of purchasers and manufacturers and avoidance of requests for numerous alternate proposals—a practice that has grown far too prevalent. Also, duplicate or repeat orders are a step toward attaining the objective.

As was pointed out during the discussion, a greater degree of standardization is possible with reference to steam conditions, exclusive of those jobs that may be classified as pioneering; and, although standardization of design is impractical as between manufacturers, it is possible within certain categories as to a single manufacturer's products, except where special conditions must be met, as is the case with many large units.

In reviewing progress over the past year—a period in which this field has been very active—one notes the fruits of accumulated experience and development over the war years, amplified by later tests and increased facilities for investigating what goes on within a unit. This information has pointed the way to rational designs of greater simplicity, more accurate control and improved availability, particularly with reference to burning the poorer grades of fuel. In the category of smaller units, as well as those of medium capacity, there has been much progress in standardizing basic designs, with departures confined to minor items. Large, heavy-duty steam generating units, however, will continue to embody special features to meet individual requirements; but even here there has been a marked trend toward fewer types and standardization of details. In this group, particularly, duplication of successful designs points the way to appreciable savings in initial costs.

However, it is not to be inferred from the foregoing that practice is likely to become static for, within certain limits, the constant urge toward further improvement will continue to function and keep pace with the ever-changing economic conditions in the field of steam generation.

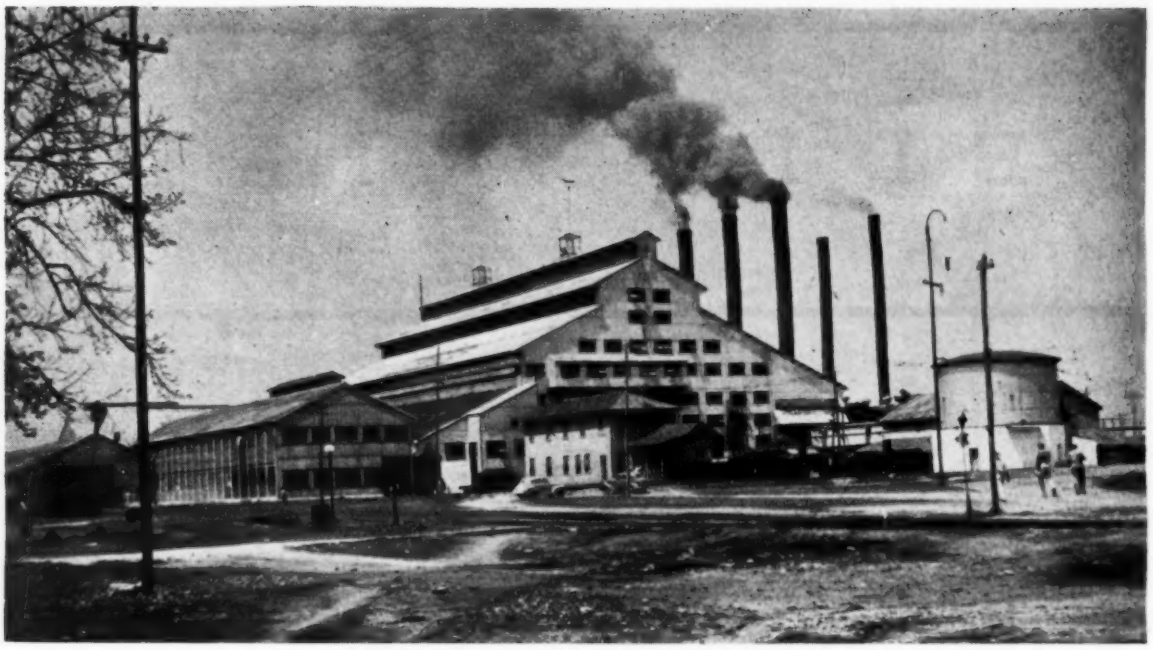

Fig. 1—Central Delicias Sugar Mill in Oriente, Cuba

Burning Bagasse at Cuban Sugar Centrals

Production of cane sugar has been carried on for so many generations in substantially its present form that changes in equipment and operation are not encountered as in more recently developed industries. The following points out some of the problems which have arisen and the methods employed to solve them, based largely on personal observations made during a recent trip by the author to Cuba. It also describes an improved method of burning bagasse with spreader stokers, which promises to revolutionize the present practice.

By H. G. MEISSNER

Combustion Engineering Company, Inc.

THE importance of Cuba in the cane sugar industry is illustrated by recent statistics showing that its 177 sugar mills or "Centrals," which extend from end to end of the 750-mile-long island, produced in the last crop year about 30 per cent of the world's total, or almost 50 per cent of the output in the Western Hemisphere which in 1946–1947 amounted to 12,326,016 tons compared with a world production of 19,071,970 tons. Increase in Cuban production during the seven years since the start of the Pacific phase of the war practically offset the loss in the Japanese, Java, Formosa and Philippine areas.

Sugar cane on a moisture- and ash-free basis contains from 10 to 17 per cent cellulose fiber and 83 to 90 per cent sugar. The bagasse leaving the last rolls of the mill is composed of about 40 per cent fiber, 1.5 to 2.5 per cent sugar, 45 to 55 per cent moisture and 1.5 to 2.5 per cent ash.

As a matter of general interest it may be in order to point out briefly that the history of sugar cane goes back to the fourth century B.C. in Northern India, where it is believed to have originated, although field culture was not practiced until several centuries later. From India the planting of cane is believed to have spread into China. Sugar in solid form dates from about 500 A.D. in Persia, the word sugar coming from the Indian term "shekar." The Egyptians developed the commercial manufacture and refining of sugar during the ninth and tenth centuries. It was first introduced into the Western Hemisphere by Columbus on his second voyage in 1494, to San Domingo, from whence it spread into Cuba and other West Indian and Central and South American countries. In 1750 its cultivation was started in Louisiana.

Milling of cane was done originally by means of wooden rollers, driven by animals, wind or water power. Cuba first introduced the steam-driven six-roller mill in 1883, and the Central Delicias in Oriente holds the world's record for production by a single mill, 1,046,000 bags of 325 lb each having been produced in the grinding season of 1922.

Steps in Production

Manufacture of raw cane sugar is a combination of mechanical and chemical processes. In the Cuban fields it starts with the hand cutting of the cane, which is simultaneously stripped and topped. It is then hand-loaded into two-wheel carts, which are hauled by oxen to sidings, where the cane is raised by ox-power winches, and deposited in specially designed narrow-gage cane cars. Tractors are now being employed to some extent.

From the primary conveyor the cane is carried up an inclined conveyor, past the leveler and knives, into the milling plant, where the juice is extracted, the rolls being forced together by hydraulic pressure to within fractions of an inch of clearance. The juice is then carried through the various processes, the end products consisting of commercial sugar, molasses or blackstrap, and press cake or cachaza.

The bagasse or crushed cane fiber is discharged from the last set of rolls, in a continuous stream, to scraper conveyors which carry it either directly to the boilers as fuel or to storage piles for subsequent use. The process is essentially continuous, 24 hr per day for the entire grinding season, which in Cuba frequently runs from January to May or June. Shutdowns are made only for emergency repairs, or periodic cleaning, and the utmost reliability and ease of maintenance of all equipment are, therefore, prime requisites.

Use of steam starts with the extraction of the juice from the cane in the tandems, which are generally engine driven, although electric drives are beginning to make their appearance. Process steam used in the refining of the juice accounts for the major part of the boiler output, about 93 per cent of the total heat in the steam generated being so used. Most of this process steam is taken from the exhaust of the mill engines and turbines.

Steam Generation

The trend in recent years has been away from horizontal return tubular boilers, formerly favored because of their supposed large water storage capacity, and toward water-tube boilers, preferably of the bent-tube type. The effective water capacity of such boilers is higher than that of the hrt type and they are capable of following plant load swings and maintaining uniform steam pressures more effectively.

Fig. 2—Sugar cane as it grows in the field

Larger boilers are also becoming more popular, capacities of 50,000 lb to 75,000 lb per hr being common, and still higher capacity units are being installed or contemplated. Boiler reliability has increased so greatly in recent years that the danger of failure is reduced, and one large boiler obviously costs less to operate and maintain than the ten small units which it may replace.

Inclusion of superheaters has been limited by the type of mill-drive engines in common use, but with the increasing installation of turbine-generators and motor drives, higher steam temperatures and pressures are being considered. The large percentage of steam used in the process work reduces the desirability of maximum efficiency in the power-generating department so that it is improbable that much progress will be made in this direction except in the case of generating equipment designed for use in the off season, when oil or baled bagasse is used for fuel, and there is no use for the exhaust steam. Some mills are now generating power for use in surrounding communities, and this practice is likely to expand. Use of a smaller number of large boilers also simplifies the bagasse-handling problem and advantage is being taken of this fact to reduce the attendant labor for handling the fuel.

When the tandems are all in operation there is a steady supply of green bagasse available, but when a tandem is down for cleaning or repairs, bagasse must be taken from the storage pile with a minimum of delay as there is little reserve supply in the furnaces. On the other hand, because of irregularities in the steam demand and other

Fig. 3—Relic of old rolls

factors, there is likely to be a surplus of bagasse at times, over and above that which can be burned or stored. Hence some mills are installing incinerators or are converting old boilers to this service, the gases being cooled by admission of excess air or water sprays. In this way the varying quantity of available fuel can be handled with a minimum of interference with the boiler operation.

In some mills plans have been made, or are under consideration, to use some of the bagasse for other than boiler fuel. Such uses include: low-grade paper suitable for mulching in cane and pineapple plantations; wall-board and insulating material; a base for certain plastic material; cattle bedding; and baling for use in locomotives during the summer.

In Louisiana many of the mills already sell much or all of their bagasse for by-product process, using the relatively cheap local natural gas for steam generation, and this market is likely to expand as such by-products are more fully exploited. But in Cuba natural gas is not available, so that the more efficient combustion of the bagasse will be the only alternative to the use of the relatively expensive imported fuel oil at certain periods. At one Central visited, plans were under way to have the planters change to a higher yield, lower fiber cane, which would mean that instead of a surplus of bagasse for the boilers, there would be a deficiency, unless the overall boiler efficiency were raised materially. There are also some by-product developments under way, which will materially increase the steam consumption. In mills where the sugar is refined before shipment, the steam consumption is increased by about 15 per cent. It can be seen, therefore, that greater efficiency in the burning of this fuel may become an important factor within the next few years.

Use of economizers and air heaters is on the increase. The latter are particularly desirable, as the hot combustion air serves to raise the furnace temperature and speed up the drying and ignition of the fuel. This quicker response to load demands assures more uniform steam pressure and higher milling capacity.

While it would be desirable to dry out some of the moisture in the bagasse before it enters the furnace so as to reduce the gas weight and boiler draft loss, such predrying has not as yet been successful, largely because of the bulky nature of the fuel and the fact that some of the combustible volatile matter distills off at quite low temperatures and would be lost in the dryer or constitute a fire hazard. It can be shown, therefore, that the use of air heaters will effect as great a saving in fuel consumption as will the predryer and that the reduction in boiler draft loss is counterbalanced by the added draft loss in this predryer. It is probable that the use of air heaters will increase as their merit becomes better known, while the combination of economizers and air heaters assures the maximum in boiler efficiency and capacity.

Bagasse Burning Practice

The fuel used in the early boiler plants consisted of wood, or sun-dried bagasse. It was not until 1886 that Samuel Fiske demonstrated, first in Louisiana and later in Cuba, that green bagasse could be burned in a boiler furnace equipped with a flat grate. About the same time Frederick Cook introduced his hearth or horseshoe-type furnace, Fig. 5, in which all the air was introduced through tuyéres, above rather than through the fuel bed.

Fig. 4—Bagasse piles adjacent to boiler house

The third step in the burning of green bagasse was the introduction of the inclined or stepped-grate furnace, Fig. 6, the fuel cascading slowly down over the grates, with air passing through the fuel bed. This type is also known as the Hofft design.

More recent developments include the Ward and the Martin furnaces, sometimes called bottle-neck furnaces because of the restriction near the top. In these furnaces the air is admitted around and over rather than through the fuel bed. Typical arrangements of these are shown in Figs. 7 and 8. The high gas velocity through the throat of the bottle-neck furnace is a source of considerable carryover of partly burned bagasse fines or bagacillo into the boiler which not only increases the frequency of cleaning, but in some cases may result in slagging of

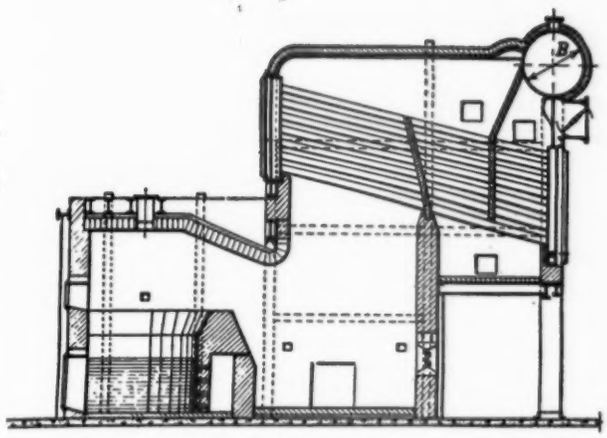

Fig. 5—Cook horsehoe furnace

tubes. This high gas velocity also causes a larger amount of the bagacillo to be carried out of the stack.

A significant step ahead is shown in the layout of Fig. 9. Here the designers applied the knowledge gained in the firing of other fuels and opened up the secondary chamber to provide space for the complete combustion of the gases before they reached the boiler tubes. Not only was it then possible to operate at greater capacity without slagging the tubes, but the ability to operate with higher air temperatures and lower excess air assured increased overall efficiency. Secondary combustion in the boiler passes of some of the earlier units was finally recognized as the cause of many of the troubles experienced, the flame in the furnace being forced into the boiler before it is completely burned out, whereas in the setting, as shown in Fig. 9, combustion is completed in the secondary chamber, and the unburned combustible losses are therefore reduced.

The various furnaces described all use a relatively thick mass of bagasse on the grate, either a pile as in the horseshoe furnace, or a sloping layer as in the inclined or stepped-grate type. Control of the fuel and air supply is usually manual and inefficient. The excess air varies widely, from 50 to 100 per cent or more in many furnaces, so that overall efficiency is low. Steam pressure control is frequently erratic; consequently engine and turbine performance is adversely affected. Cleaning of the grates, hearths and boiler passes is a hot and laborious job and in many cases the boilers must be taken out of service weekly for removal of fly ash and clinkers and for furnace repairs. The net result has been that the average boiler output is low, and additional boilers must be kept in operation with attendant higher labor cost.

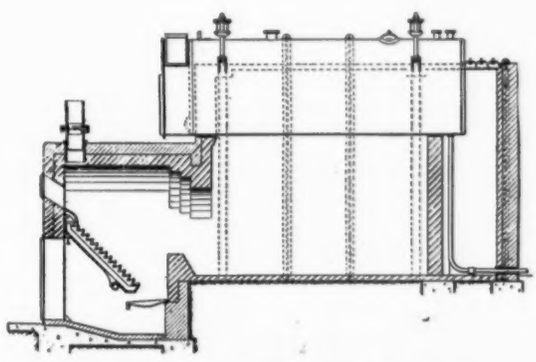

Fig. 6—Inclined-grate with hrt boiler

Aside from the relatively minor changes in furnace and grate design noted above, and the use of forced rather than natural draft in some of the newer furnaces, there has been no real improvement in the burning of bagasse for many years, whereas the art of burning many other fuels has made tremendous strides. The opportunity for a change for the better is therefore apparent.

Spreader Stoker Firing

Recent introduction of the spreader stoker into this field has completely revised the concept of the proper method of firing such high-moisture fuels. This type of stoker has been in general use for many years, but until recently it has been employed almost exclusively for the burning of bituminous coal and lignite, with a few in-

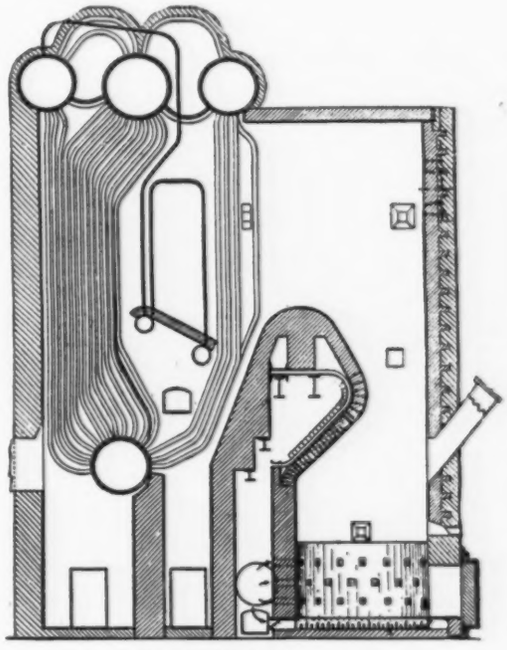

Fig. 7—Ward furnace

stallations applied to the firing of wood chips, hogged fuel and similar refuse material.

The fibrous, tenacious and bulky nature of bagasse, in addition to its high moisture content, has made it impossible to handle with the conventional spreader stoker; hence a special type of feeder and distributor had to be developed before this fuel could be successfully burned. With the perfection of this improved equipment and technique, the well-known advantages of spreader-stoker firing can now be applied for the first time in the cane sugar industry to the firing of both boiler and incinerator furnaces.

The illustration, Fig. 10, shows the application of this combustion system to a two-drum boiler. The green bagasse discharged from the end of the mill or tandem in a continuous stream or the reclaimed bagasse from the storage pile keeps the hopper mounted below the conveyor full at all times, surplus bagasse being carried along to the next furnace or to storage. The specially designed rotary feeder, the speed of which may be automatically

controlled, meters the fuel required to maintain uniform steam pressure, to the rotary distributor located at the bottom of the inclined chute. Blades angularly welded to the distributor drum project the fuel into the furnace in a thin, uniform and widely dispersed stream.

The bagasse particles are flash dried as they enter the hot furnace gas stream, and either drop onto the grate to complete their combustion or are burned in suspension, depending on their size and moisture content. The fuel bed is thin, uniform and actively burning all over the grate, there being no piles or dead areas. Combustion is, therefore, very rapid and complete, the fuel bed burning to a clean, light ash with a minimum of excess air. Hot refractory being unnecessary to ensure drying and ignition of the bagasse, the stoker grate is located directly in the boiler furnace which may be water cooled or of refractory design. The grate surface is continuous across the length and width of the furnace, there being no partition walls or other space-consuming refractories. This grate surface may, therefore, be of whatever size is required to fit the furnace dimensions, within reasonable limits. The feeder and distributor units are also variable in number and

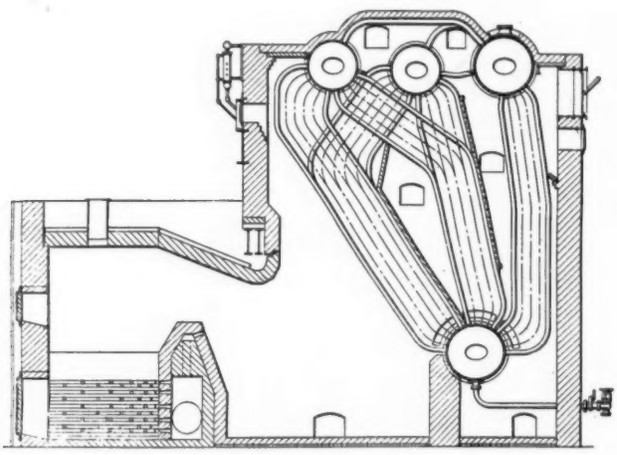

Fig. 8—Martin furnace

spacing so that this bagasse combustion system may be applied equally well to new or to existing boiler furnaces. The grates may be of the dumping or continuous ash-discharge types, as desired.

The resultant advantages compared with the problems encountered in the existing furnaces as noted above are so significant that wide adoption of this new technique is anticipated by cane sugar mills. These advantages may be summarized as follows:

Bagasse burning efficiency is increased as much as 15 to 20 per cent. The thin, uniform fuel bed, and introduction of practically all the air through the grate, facilitate the control of the fuel-air ratio, either manually or automatically so that excess air losses are greatly lessened. Tests have shown that this excess air may be reduced to as low as 15 per cent corresponding to about 17 per cent CO_2, as compared with the more usual value of 50 to 100 per cent. The increased overall efficiency, because of this saving, together with the decreased carbon and radiation losses which accompany it, are on the order of 15 to 20 per cent.

The ease with which automatic combustion control equipment can be utilized results in the maintenance of

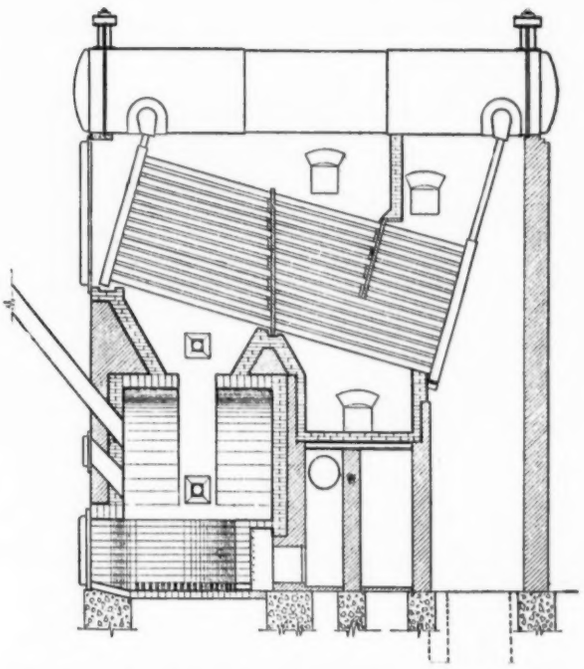

Fig. 9—Secondary chamber enlarged to provide adequate combustion space

more uniform steam pressure, thus eliminating the loss of water through the safety valves, improving performance of the engines, turbines and pumps, and reducing the use of auxiliary fuel oil. Boiler room labor requirements are also reduced to a minimum.

As a smaller number of boilers operating at their most efficient output may be employed, spare boiler capacity becomes available. Boiler and furnace availability is greatly improved, as the stoker-fired boiler may be kept on the line continuously throughout the grinding season. The dumping-grate type stoker can be cleaned in a matter of minutes, with little or no loss in boiler output, and the continuous ash-discharge type of grate maintains a clean fire at all times.

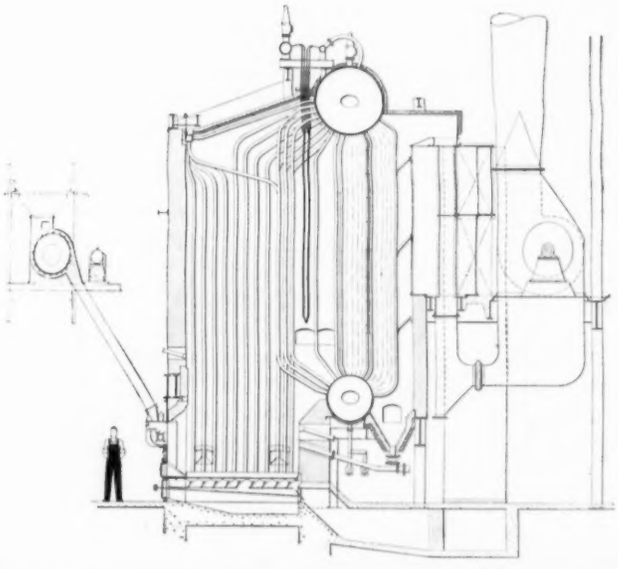

Fig. 10—C-E spreader-stoker firing system applied to two-drum boiler

Boiler and furnace maintenance is materially reduced. Installation of the stoker directly in the boiler furnace eliminates much of the troublesome refractory walls and arches, and avoidance of excessive inrush of cold air during the cleaning periods cuts down boiler expansion stresses and leakage and minimizes spalling of the brickwork.

The open furnace design provides a maximum volume in a given space so that the gas velocities are low, and cinder or bagacillo carryover is minimized. Complete water cooling can be employed, and the installation of auxiliary gas or oil burners is facilitated.

The cinder recovery system returns the carryover to the furnace for reburning so that stack emission is greatly reduced.

Starting of fires is readily accomplished by the use of oily waste or small kindling near the furnace front, from which point the fire quickly spreads as the fuel feed and forced draft are started. There is no need to first heat up the furnace with wood or oil, as is necessary with the dutch-oven furnaces.

Elimination of the dutch-oven extension, partition walls, arches and special refractory shapes greatly reduces the space requirements, material cost and labor for erection.

As this bagasse combustion system has been specifically designed to fit into the average sugar mill layout, its use presents no difficult problems in application, and its field, therefore, encompasses virtually the entire cane sugar industry.

Hot-Process Conditioned Water for High-Pressure Boilers

By A. C. Dresher*

The tendency that has prevailed over a number of years toward higher boiler operating pressures has highlighted four important requirements for satisfactory boiler feedwater which are, in general, obtainable with the hot-process type of water conditioning equipment. These are:

1. Zero Hardness. This is required to completely eliminate sludge and scale formation in the boiler. It means reduction considerably below the indication of so-called "zero hardness" by the soap test. With low hardness supplies having less than 50 ppm of hardness, this can be accomplished by using phosphate and caustic soda as the reagents. With hard water supplies a two-stage softener utilizing cheaper lime and soda ash as the initial treatment followed by phosphate to precipitate the residual hardness externally is generally recommended.

2. Low Total Solids. Water having a low concentration of total solids has always been a requirement of properly prepared boiler feedwater. The goal is to provide a makeup water that approaches distilled water as nearly as is economically possible. Low total solids are desirable to minimize boiler blowoff loss and also to reduce carryover with the steam and the resultant erosion and deposits in steam-using equipment.

3. Low Concentrations of Silica. Since all waters contain silica, often in amounts that would bring about a prohibitive concentration of silica in the boiler, much attention is now being directed toward its reduction. Silica, even in low concentrations, is apt to volatilize, be carried over with the steam, and solidify on turbine blades causing loss of capacity and efficiency. Even good waters contain a silica concentration of approximately 5 ppm, and, if a plant is designed on the basis of 5 per cent or 10 per cent blowdown, the concentration of the silica in the boiler will be 20 to 10 times, concentrating to an extent of 100 ppm or 50 ppm. The removal of silica in the hot-process softener is accomplished by coagulation and precipitation using magnesium salts, either initially present as hardness in the raw water or added for the specific purpose. Recirculation of the precipitated sludge from the accumulation in the sludge cone makes maximum economical use of the reagents.

4. Low and Controllable Alkalinities. Although it is common for low-pressure boilers to operate with boiler alkalinities of 300 to 1000 ppm, the alkalinities permitted in high-pressure steam generators are ordinarily limited to 150 ppm or even less. This is desirable because low alkalinities produce a sufficiently high pH value to protect the boilers against corrosion; any increase in alkalinity over that necessary to prevent corrosion simply adds to the total solids, increases the blowdown schedule, and is likely to increase the carryover tendencies of the boiler concentrate.

To meet these objectives a number of general types of equipment are available which, when properly selected and coordinated, will produce a satisfactory water supply and may even approach distilled water under some conditions.

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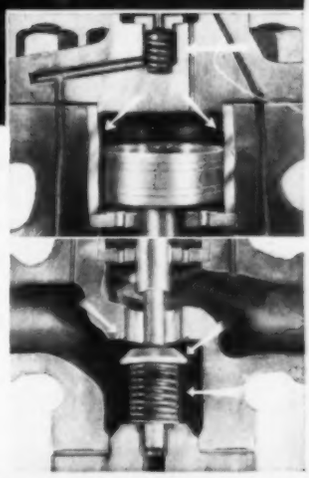
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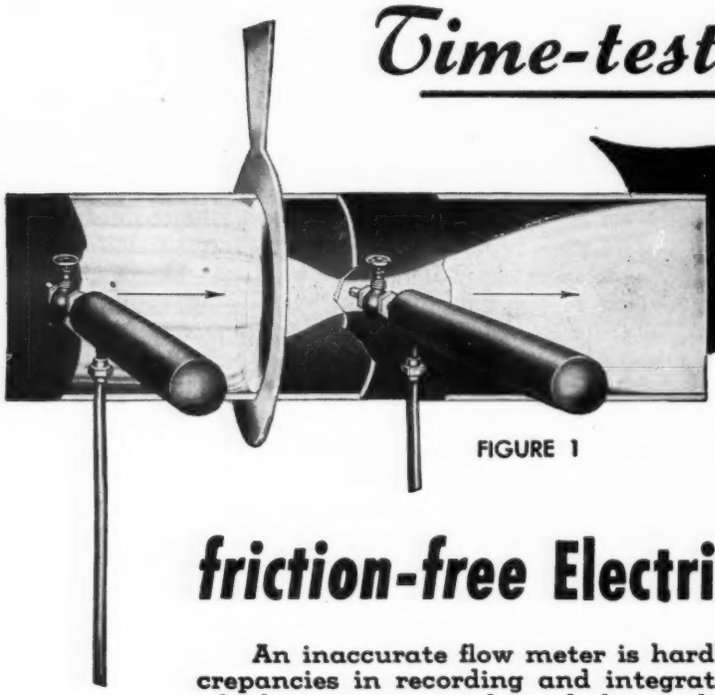

FIGURE 1

An inaccurate flow meter is hardly better than a good guess. Even slight discrepancies in recording and integrating flow can make valueless the records on which management depends for vital data.

In the Hays-Cochrane meter high accuracy is achieved by eliminating as much friction as is humanly possible and by applying sufficient power to compensate for the small amount of friction remaining.

The H-C transmitter (Figure 2) contains a mercury U-Tube, a non-metallic float on the mercury in the high pressure leg, two reactance coils, and a magnetic core supported by the float and positioned by differential pressure produced by orifice, nozzle or venturi in the pipe line (See Figure 1).

The Receiver (Figure 3), like the transmitter, contains two reactance coils and a core. A change in flow produces differential pressure change which moves float and core on the mercury surface of the Transmitter. Reactances of transmitter and receiver coils are thus unbalanced and a current flows through the galvanometer in the receiver, deflecting its boom. Indicator pointer, pen arm and integrator simultaneously show flow rate changes. This is accomplished with movement of the receiver core through a synchronous-motor-operated mechanical relay, which causes the galvanometer to regain null balance.

FIGURE 2
TRANSMITTER

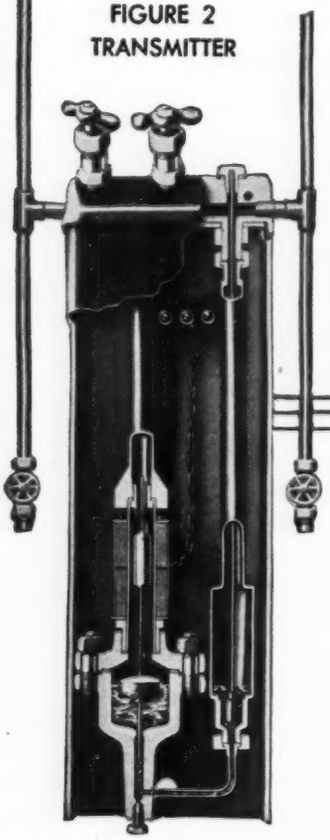

FIGURE 3 RECEIVER

There is no possibility of friction in the Hays-Cochrane Transmitter because there are no stuffing boxes, bearings, linkages or gears—merely a free-moving float positioning a core within a magnetic coil. The detecting circuit is not required to move any working parts other than the finely balanced galvanometer boom. These (indicating, recording and integrating mechanisms) are operated by a synchronous motor.

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Behavior of Ash in Pulverized-Coal-Fired Furnaces

This article[1] summarizes what is known of the fundamental flow properties of coal-ash slags and of the behavior of ash and slag deposits on heat-absorbing surfaces, and presents methods for applying the available data on ash and slag to practical problems of interest to operators and designers. An outline is given of a comprehensive research program, comprising field and laboratory studies, which should go far toward placing, on a scientific basis, the evaluation of the effect of ash on furnace performance.

By P. COHEN* and R. C. COREY†

DESPITE the considerable amount of fundamental and engineering research in fuel technology that has been done since the classical combustion investigations made by Henry Kreisinger at the Bureau of Mines, the design and application of equipment for burning coal is not yet an exact science and must depend largely on empirical and cut-and-try methods. The principal gap in our knowledge in this respect is fundamental information on the properties and the behavior of coal ash. This situation is not an indictment of research progress in fuel technology, or of the engineering skill of the boiler designer; rather it attests the extremely complex nature of the events in a furnace between the time the coal is ignited and the ash is discharged.

Analysis of the operating problems of large steam generetors reveals that the most frequent causes of boiler outage, and consequent lowered availability, are excessive draft losses and overheating and failure of superheater elements and generating tubes, due to accumulations of ash and slag in the gas passages and on heat-absorbing surfaces. Of minor occurrence, but nevertheless of real concern to operators, are the sudden, unpredictable fluctuations of fluid flow in the water-wall and generating circuits as a result of marked changes in local rates of heat transfer when slag and ash accumulations are shed from heat-absorbing surfaces nonuniformly and suddenly.

Ash and slag problems are an accepted nuisance in power plants. However, the recent trend away from wet-bottom pulverized-coal units in favor of the conservatively designed dry-bottom type,[2] which experience has shown generally to have a higher availability, is an indication that operators are making an effort, despite higher capital costs, to minimize ash problems by adopting designs in which lower furnace-heat release rates are obtained. Thus, conservative design, rather than the policy followed during the 'thirties of squeezing as much coal as possible into as small a combustion space as possible, is a step in the right direction toward increasing boiler availability and promoting greater use of cheaper fuels. However, until more information is available on the properties and the behavior of the mineral matter after the coal substance has been burned, the basis for certain phases of furnace design, such as the arrangement of the tube banks for boiler and convection surfaces, and the proper balance between evaporating and superheating surfaces, will continue on an empirical basis. One reason for this is that almost nothing is known of the mechanism of the adherence of ash particles to radiant and convective surfaces in boilers.

For example, the changes that occur during heating of the petrographic constituents in the ash and their relation to the "stickiness" of the ash should be determined. At present, research groups in England are actively investigating these factors in an effort to increase the availability of overloaded and rapidly depreciating steam plants. In this country, one of the objectives of the Special Research Committee on Furnace Performance Factors of the A.S.M.E. is to study ash problems related to furnace performance by means of tests on various types of boilers under operating conditions, and on a laboratory basis by means of investigations of the thermal conductivity of coal ash and slag and studies of the progressive changes during heating of the petrographic constituents comprising the mineral matter in coal.

Our present knowledge of the properties and behavior of coal ash is relatively meager, despite many years of intensive study by private and government research groups, and consists principally of the results of studies of the relations between the chemical composition of coal ash and viscosity, clinkering, and fusion characteristics. Some field studies also have been made of classification and segregation in boilers of the individual components of coal ash, but data available are inadequate for obtaining more than a qualitative correlation between laboratory results and the behavior of ash in the furnace.

Therefore, in order to clarify the status of our knowledge of coal ash, in so far as it is related to the behavior of ash and slag in pulverized-coal-fired furnaces, it is the purpose of this paper to summarize what is known of (*a*) the fundamental flow properties of coal-ash slags, (*b*) the behavior of ash and slag deposits on heat-absorbing surfaces, and (*c*) the means for applying the available data on ash and slag to practical problems of interest to operators and designers.

[1] Published by permission of the Director, Bureau of Mines, United States Department of the Interior, Washington, D. C.

* Fuel Engineer, Bureau of Mines, Central Experiment Station, Pittsburgh, Pa.

† Supervising Engineer, Combustion Research Section, Bureau of Mines, Central Experiment Station, Pittsburgh, Pa.

[2] "A Fuel Engineering Study of Some Recent Boiler Installations," J. E. Tobey; Panel Discussion, "Improved Application of Coal Burning Equipment," Annual Meeting of A.S.M.E., December 3, 1946. (Orders contracted for during 1945 and 1946 show a ratio of dry-bottom to wet-bottom units of 6.5:1.)

Properties of Coal-Ash Slags

COMPOSITION.

Coal-ash slags are composed essentially of silica, alumina, iron oxides, lime and magnesia, with minor quantities of the oxides of phosphorus, titanium and alkali metals. The composition of the original ash may vary over a wide range with respect to silica, alumina and iron oxides, depending on the source of the coal. For any given coal, however, wide variations in the composition of the ash and slag may occur as the result of the classifying action that occurs in the furnace. For example, although the original coal ash may contain the order of 0.001 per cent[3] of arsenic, expressed as As_2O_3, deposits on secondary heating surfaces have been found to contain as much as 15 per cent As_2O_3. It will be shown later that the natural classifying action in a furnace greatly limits the utility of the standard A.S.T.M. cone-fusion values for a given coal ash, since the composition of the ash from a particular surface in the furnace or boiler may be quite different from that in the coal.

VISCOSITY OF LIQUID SLAGS

Any coal ash, when heated to a sufficiently high temperature undergoes chemical reactions that lead to the formation of a liquid slag. The viscosity of this liquid varies with temperature as represented by equation

$$\eta^{-z} = At - B, \qquad (1)$$

in which η is the viscosity in poises, t is the temperature in deg F, and A, B and z are parameters. The parameters z and A are practically constant over the range of coal-ash slags so far studied and have average values of 0.1614 and 0.000452, respectively. Fortuitously, this reduces equation (1) to one containing a single parameter, B. Therefore, if the viscosity of a slag is known at one temperature, the entire viscosity temperature relationship for the liquid slag can be calculated. The nomogram shown in Fig. 1 is based upon this equation and readily gives the viscosity of a liquid slag at any desired temperature if the viscosity is known at a particular temperature. The additional scale at the right side of the figure permits calculation of the viscosity at 2600 F, an arbitrarily selected base temperature, if the chemical composition of the slag is known. Therefrom, the viscosity of the same slag at any other temperature can be determined.

It has been found more convenient to characterize slags in terms of their viscosity at 2600 F, (η_{2600}), instead of the parameter B, regardless of whether the slag is liquid at that temperature.

FLOW CHARACTERISTICS OF COAL-ASH SLAGS IN THE SOLIDIFICATION RANGE

When a slag is cooled from a temperature at which it is completely liquid, the viscosity increases according to equation (*1*). At a certain temperature, defined as the *liquidus* temperature, crystals of a composition usually different from that of the mother liquid begin to separate. The process is very similar to that which occurs during the cooling of ordinary lead-tin solders from above the

[3] "Rare and Uncommon Chemical Elements in Coal," F. H. Gibson and W. A. Selvig: Tech. Paper 669, Bureau of Mines, 1944. Government Printing Office, Washington, D. C., 15 cents.

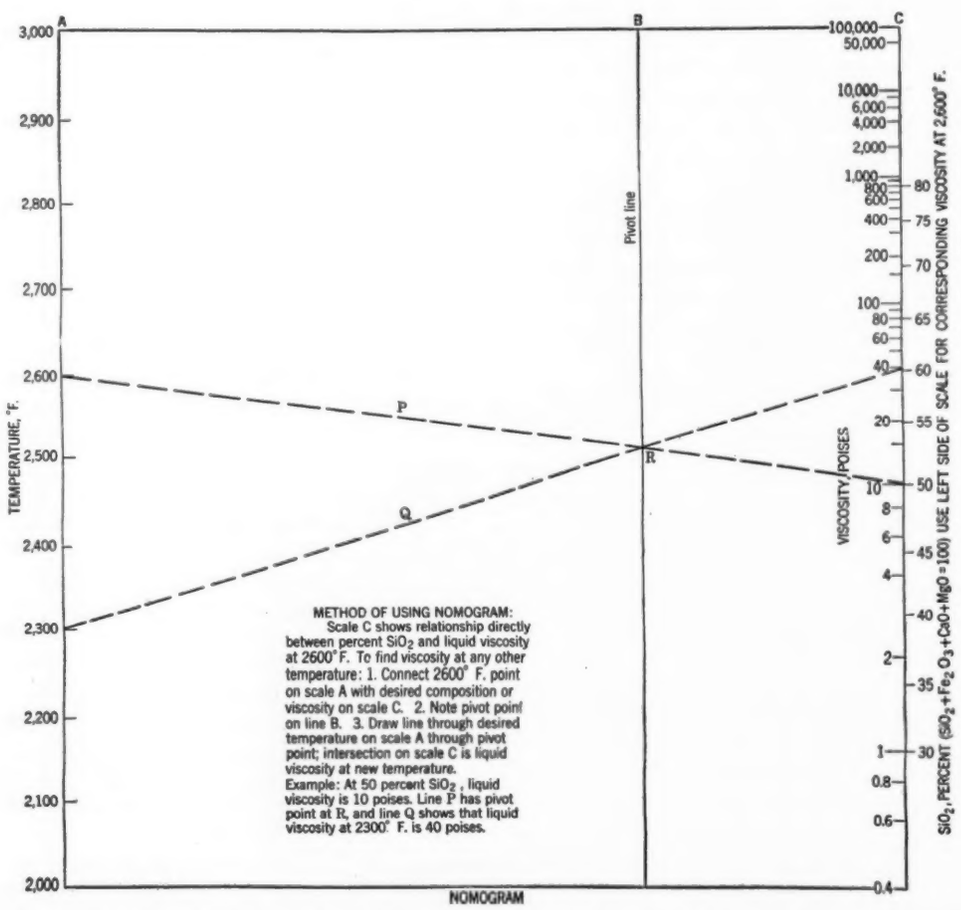

Fig. 1—Viscosity of coal-ash slags in the liquid state as a function of composition and temperature

melting point, where the crystals which separate during cooling cause the mass to go through a "mushy" stage before the entire mass solidifies. The increase in viscosity when a liquid slag cools is the net result of a progressive change in viscosity of the liquid phase, due to the change in composition as crystals separate, the presence of crystals suspended in the liquid phase, and the increase in viscosity of the liquid phase in accordance with equation (*1*). As the latter is the predominant effect and masks the other two, a continuous, smooth viscosity-temperature curve is obtained for some temperature interval below the liquidus temperature. At a definite temperature for each slag, however, the accumulation of crystals causes an abrupt change in the flow properties of the slag, owing to the fact that at temperatures below this critical temperature the slag has plastic rather than viscous flow properties. This temperature is called the *temperature of critical viscosity*, T_{cv}, and is of the greatest significance because, for low shear stresses, the apparent viscosity at temperatures below T_{cv} will be quite high and will increase rapidly as the temperature decreases.

In Fig. 2 flow curves are shown for two typical slags over the entire temperature range of interest. The radical change in flow properties at T_{cv} is evident. The freezing temperature of slags, or the freezing interval, is also of considerable interest. The slags of Fig. 2 differ considerably in this respect, slag *X* freezing between 2420 and 2300 F, or a range of 120 deg F, and slag *Y* over a range of 300 deg F.

The temperature of critical viscosity and the freezing temperature are functions not only of the ultimate composition of the slag but also depend on the state of oxidation of the iron in the slag. The latter is conveniently expressed as the *ferric percentage*, which is defined as

$$\text{Ferric percentage} = \frac{100 \times Fe_2O_3\%}{Fe_2O_3\% + 1.11\ FeO\%}. \quad (2)$$

Thus, it is the percentage of the *total* iron in the slag calculated to Fe_2O_3 that is actually present in the ferric state, an independent analysis being made for the ferrous iron in the slag. Fig. 3 shows the effect of composition and ferric percentage on T_{cv} of coal-ash slags, and Fig. 4 is a similar plot for the freezing temperature. Both plots are for slags with a silica : alumina ratio of 2.0 and cover the composition range of 15 to 40 per cent total equivalent Fe_2O_3 and 0 to 20 per cent (CaO + MgO). The extreme importance of the iron oxide content of slags will be appreciated from the fact that, as shown in Fig. 3, a slag having 10 per cent (CaO + MgO) and 40 per cent total equivalent Fe_2O_3 shows a variation in T_{cv} of almost 500 deg F for changes of ferric percentage from 15 to 73 per cent. A correspondingly large variation in the freezing temperature of the same slag, over the same range of ferric percentage, may be noted in Fig. 4.

Flow of Coal-Ash Slags on Furnace Walls

Examination of a section of sheet slag from the wall of a slag-tap furnace often gives a visual indication of the flow process. Fig. 5 represents graphically the cross-section of slag from a furnace-wall tube of a unit operated at about 1350 psi. Immediately adjacent to the surface of the tube is a thin, porous, irregular layer of sintered ash, through which the slag is attached to the tube. Next is a dense layer of black slag with a dull appearance, which, when examined in thin section under a microscope, is found to contain well-formed crystals. This layer comprises the greatest part of most slags. Finally, there is a layer of dense slag that generally is easily distinguishable from the crystalline layer because of its brighter, glasslike appearance. The boundary between these two layers usually is sharply defined.

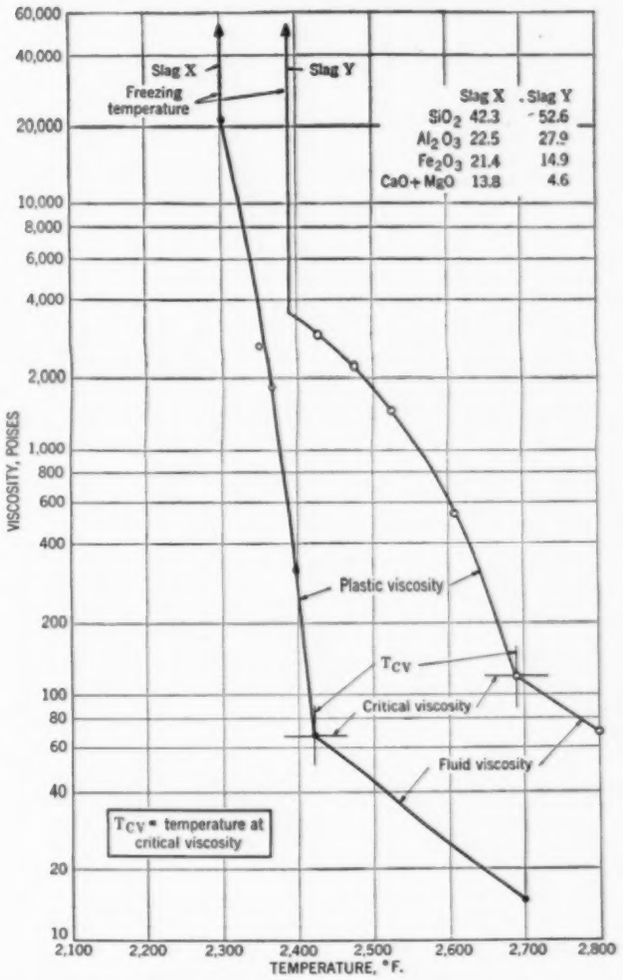

Fig. 2—Effect of cooling on solidification of two tpyical coal-ash slags, showing critical viscosity and region of plastic viscosity for equilibrium conditions in air

The fact that the glassy portion of the slag is outermost is the result of the temperature gradient through the slag which existed during the operation of the furnace, and not of the manner in which the slag cooled when the furnace was taken off the line. If the boundary of the moving layer extended to the tube surface during operation of the furnace, rapid cooling of the slag close to the relatively cold tube would quickly freeze the slag, with the result that either the entire cross-section would have a glassy appearance or the relative position of the layers shown in Fig. 5 would be reversed. It appears, therefore, that, under operating conditions in the furnace, the inner portion of the slag is at a sufficiently low temperature for crystals to separate and that a certain portion of the slag on the furnace side is molten.

For practical purposes, where the shear stress in the slag is relatively low, as by the action of gravity on a vertical wall of slag, the point at which T_{cv} occurs in a slag deposit represents an abrupt change in physical properties; slag at lower temperature behaves essentially as a solid, while hotter slag flows as a liquid. It is

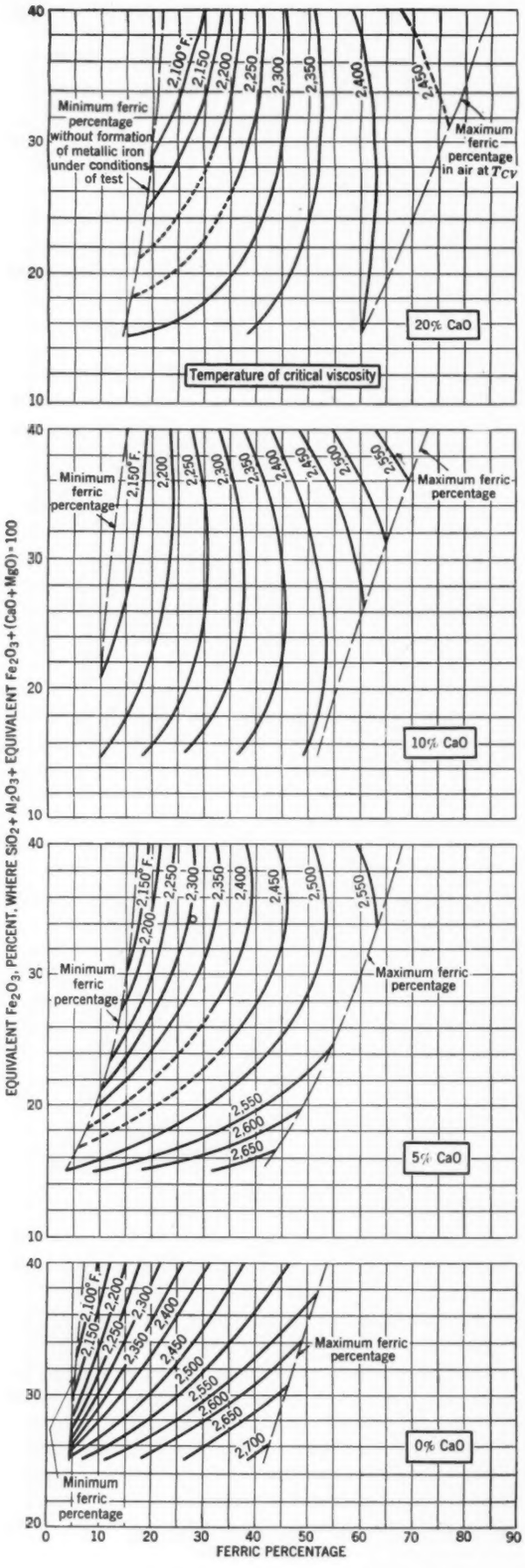

Fig. 3—Temperature of critical viscosity of coal-ash slag as a function of composition and ferric percentage, for a silica-to-alumina ratio of 2

reasonable to assume, therefore, that the boundary between the crystalline, stationary layer and the glassy, flowing layer of slag on furnace walls occurs at the temperature of critical viscosity, while the high-temperature boundary will be at the furnace temperature, t_f. Thus, there will usually be a temperature difference of several hundred degrees between the two sides of the layer. The viscosity of the liquid slag and its variation with temperature will determine the thickness of the liquid layer required to carry off the slag being supplied.

The flow properties of the slag that are important in fixing the thickness of a slag deposit on a heat-absorbing surface are, therefore: (1) the temperature of critical viscosity, because it fixes the lower temperature of the flowing layer and determines the fraction of the total deposit that effectively will be solid, and thus can be considered to be fixed in position; and (2) the relationship between temperature and viscosity in the liquid layer, which will control the rate at which the slag can flow to cause a decrease in the overall thickness. As the temperature of critical viscosity increases, the fraction of the total deposit of slag that is stagnant will also increase, and the thickness of the deposit will be greater. Likewise, as the viscosity of the liquid layer of slag increases at any fixed temperature, the rate of flow of slag will decrease, and the thickness of the deposit will increase. Factors other than the flow properties of coal-ash slag also are important in fixing the thickness of slag on heat-absorbing surfaces. These include: (1) the temperatures in the furnace and of the furnace side of the slag deposit, (2) the quantity of slag being supplied to the surfaces per unit time from the furnace gases, (3) the height in the furnace at which flow begins, (4) the height at which the thickness of slag is to be considered, (5) the angle of inclination of the flowing slag (essentially that of the wall), (6) the thermal conductivity of the slag, and (7) its density.

The point of major interest is, of course, the rate of heat transfer from the furnace through the slag to the tubes. For a given temperature difference across the slag deposit, the rate of heat transfer is proportional to the thermal conductivity of the slag divided by the thickness of the slag. Although there is no precise information at present on the thermal conductivity of coal-ash slags, a coefficient $K = 10$ Btu in./hr ft^2 °F may be used as a rough average value. As a first approximation, this factor can be assumed to be independent of composition, temperature, and the relative proportions of liquid and solid slag; therefore the relative rates of heat transfer through the deposits can be obtained from their overall relative thickness. That is, the rate of heat transfer through slag at a given surface temperature may be considered to vary only with the thickness of the coating.

Because of the uncertainties introduced by a lack of precise knowledge of some of the factors affecting the heat transfer through slag deposits, and because of the considerable variation in the rate of slag supply to the different parts of the furnace walls, emphasis must be placed on the thickness of slag deposits for a given set of slag properties and furnace conditions, the rate of slag supply in each case being the same. Based on these considerations, an equation has been derived giving the thickness of slag deposits obtained with varying slag properties and furnace conditions, relative to the thickness of a slag having a viscosity of 100 poises at 2600 F and $T_{cv} = 2600$ F.

Fig. 6, similar in form to Fig. 3, shows lines of equal relative thickness of deposit for a furnace temperature, t_f, of 2800 F and a wall temperature, t_w, of 1200 F, for slags having a silica : alumina ratio of 2.0, Fe_2O_3 from 15 to 40 per cent, and (CaO + MgO) of 5 and 10 per cent. These curves were calculated from the viscosity data of Fig. 1 and the T_{cv} data of Fig. 3, and they show directly the thickness, relative to that of the standard slag, of slag deposits in the range of compositions covered. The marked effect of iron oxide content and ferric percentage on thickness of slag deposits is evident from this figure.

More detailed information on the flow properties of coal-ash slags over a wide range of temperatures and compositions may be found in four papers published by the Bureau of Mines[4, 5, 6, 7].

The Behavior of Ash in Furnaces

Segregation of Ash Constituents

The segregation of the constituents of the ash during firing is the major complication of attempts to correlate the behavior of ash in furnaces with the properties and composition of the ash in the coal. A study in 1933 by Nicholls and Reid[8] of slags from eighteen slag-tap furnaces burning a wide variety of coals, indicated an average ratio of the iron in the slag to the iron in the ash of 1.11; the corresponding ratio for lime was 1.13. Another selective action noticed was a ten per cent increase in the silica : alumina ratio of the slag, compared to that of the ash of the coal fired. The alkalis in the slag also invariably were lower than in the original ash.

Studies by Bailey and Ely[9] of seven dry-bottom and eight wet-bottom furnaces have demonstrated the progressive variation of the iron content of ash and slag in the gas path in slag-tap and dry-bottom furnaces. The ratio of the iron content of the slag to the iron content of the ash in the coal fired averaged 1.67 for the slag-tap furnaces, with a low value of 1.42 and a high value of 1.89. For dry-bottom furnaces the ratio averaged 1.31, with a low of 1.00 and a high value of 1.68.

State of Oxidation of Ash and Slag in Furnaces

The degree of oxidation of the iron in the ash and slag varies considerably with the position in the furnace. Nicholls and Reid[8] found the ferric percentage of the tapped slag to vary from 2.1 to 34, with an average of 16. The ferric percentage of the fly ash was high in all instances, averaging about 75. There was no apparent connection between the ferric percentage of the slag and its chemical composition, nor with the heat release per unit area. Bailey and Ely[9] reported the variation in ferric percentage with position in the furnace for a two-stage, slag-tap furnace. The ferric percentage was 39 for the slag on the primary furnace walls, 19 for the tapped slag, 24 for the walls of the secondary furnace, 42 on the first row of screen tubes, and 79 at the top of the boiler

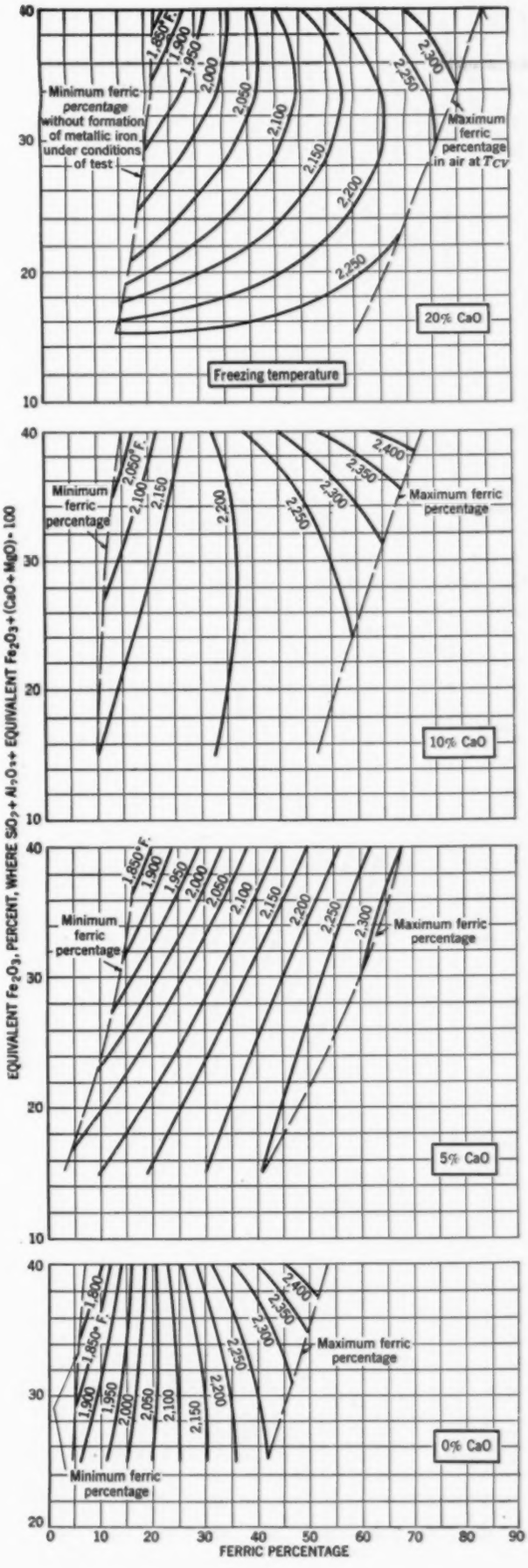
EQUIVALENT Fe_2O_3, PERCENT, WHERE SiO_2 + Al_2O_3 + EQUIVALENT Fe_2O_3 + (CaO + MgO) = 100
Minimum ferric percentage without formation of metallic iron under conditions of test
Maximum ferric percentage in air at T_{CV}
Freezing temperature
20% CaO
10% CaO
5% CaO
0% CaO
Minimum ferric percentage
Maximum ferric percentage
FERRIC PERCENTAGE

Fig. 4—Freezing temperature of coal-ash slags as a function of composition and ferric percentage, for a silica-to-alumina ratio of 2

[4] "Viscosity of Coal-Ash Slags," P. Nicholls and W. T. Reid: *Trans.* A.S.M.E., vol. 62, 1940, pp. 141–153.

[5] "Flow Characteristics of Coal Ash Slags in the Solidification Range," W. T. Reid and P. Cohen: published in pamphlet, "Furnace Performance Factors," A.S.M.E., May 1944, pp. 83–97.

[6] "The Flow of Coal-Ash Slag on Furnace Walls," P. Cohen and W. T. Reid: Tech. Paper 663, Bureau of Mines, Govt. Printing Office, Washington, D. C., 15 cents.

[7] "Factors Affecting the Thickness of Coal-Ash Slag on Furnace-Wall Tubes," W. T. Reid and P. Cohen: *Trans.* A.S.M.E., vol. 66, 1944.

[8] "Slags from Slag-Tap Furnaces and Their Properties," P. Nicholls and W. T. Reid: *Trans.* A.S.M.E., vol. 56, 1934, pp. 447–465.

[9] "Significance of Coal-Ash Fusing Temperatures in the Light of Recent Furnace Studies," E. G. Bailey and F. G. Ely: *Trans.* A.S.M.E., vol. 63, 1941.

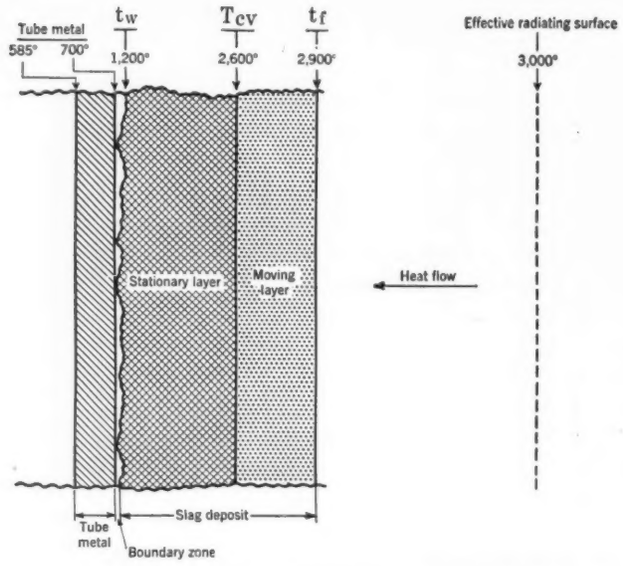

Fig. 5—Temperature distribution in slag deposit

bank. The total gas travel was about 60 ft. Thus, it is apparent from these wide variations that standard A.S.T.M. cone-fusion data for coal ash are not significant for estimating the behavior of ash and slag in certain parts of a pulverized-coal furnace. Proposals have been made to modify the A.S.T.M. procedure to include determination of the fusion characteristics of the ash under fully oxidizing conditions.

Recovery of Ash and Slag in Furnaces

The quantity of ash or slag retained in the furnace of a large boiler is of considerable practical importance. The gas-borne material leaving the furnace is in a form requiring relatively expensive equipment for its separation where that is required and presents a difficult disposal problem. Considerable work has been done on methods for separating fly ash from flue gases, and the utilization or disposal of such ash, but this phase of boiler operation is beyond the scope of this paper and will not be discussed here. Recent efforts have been devoted to means for increasing the retention of ash or slag in the furnace as a more economic solution to the problem. Depending on coal properties, design factors and operating conditions, dry-bottom furnaces may retain up to 30 per cent of the ash in the coal, in the form of sintered ash. In conventional slag-tap furnaces, the ash retained in the furnace, mostly as slag, is increased to 40 or perhaps 50 per cent. In the cyclone burner furnace, recently reported,[10] this has been increased to about 82 per cent.

Practical Applications

Criteria for Tapping Slag and Thickness of Slag Deposits

Slags of a wide range of properties have been tapped successfully from intermittent- and continuous-tap wet-bottom furnaces. Occasionally, when slag has shown signs of accumulating excessively in a furnace, despite burner and air adjustments, fluxes have been added to promote tapping; but the flexibility of modern furnaces is sufficient to make such additions generally unnecessary.

To insure adequate tapping from a furnace, two criteria should be observed: the temperature of the slag should be at least 150 deg F above T_{cv}, and the viscosity of the slag at the tapping temperature should not exceed

[10] "The Horizontal Cyclone Burner," A. E. Grunert, L. Skog and L. S. Wilcoxson: *Trans.* A.S.M.E., vol. 69, 1947, pp. 613–634.

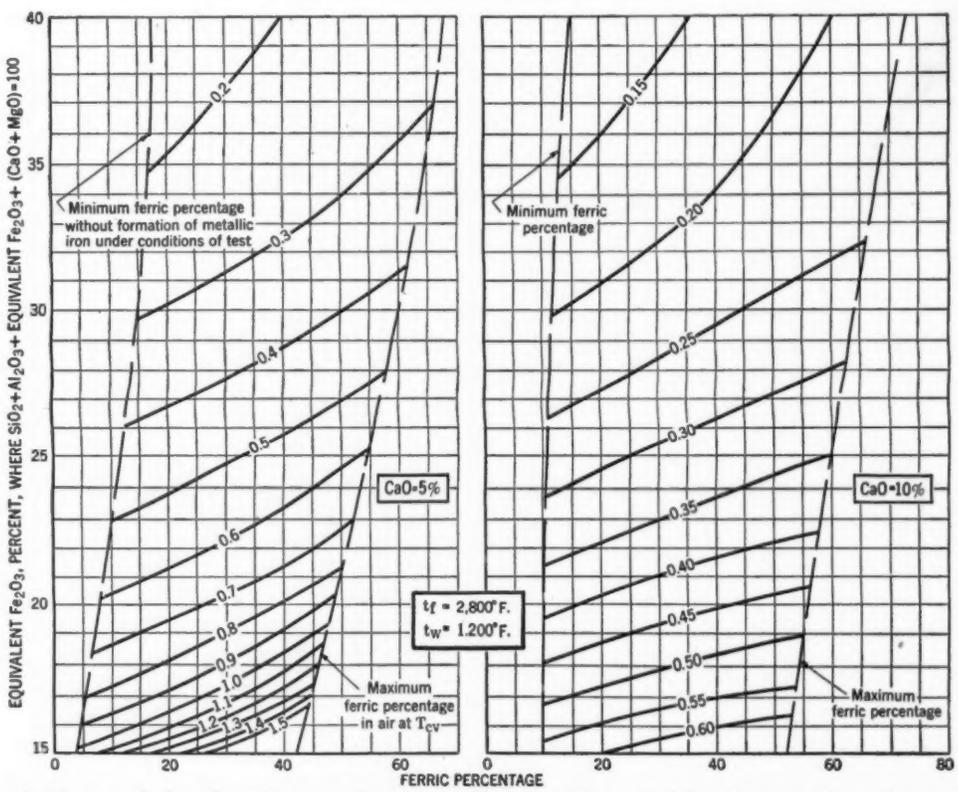

Fig. 6—Relative thickness of slag deposits as a function of composition and ferric percentage for a silica-to-alumina ratio of 2

250 poises. Neither of these factors alone is sufficient to obtain satisfactory tapping, since if only the temperature of the slag above T_{cv} is considered, the viscosity of the slag may still be excessive, and if only the viscosity at the tapping temperature is considered, the freezing interval of the slag may be so narrow that a moderate reduction in the boiler load will cause tapping to cease, with possible serious consequences.

To the authors' knowledge, there is as yet no *a priori* method for calculating the temperatures in slag-tap furnaces solely from consideration of the properties of the ash. Furnace designers must make estimates, for design purposes, of the temperatures of gases leaving the furnace, but these are based largely on previous experience, with wide latitude for control and regulation of superheat. In the present state of the art, the application of the knowledge of the properties of slags must be restricted to relative studies. Thus, if the performance of a particular furnace is known for a given set of operating conditions, it is possible to estimate the effect of changing the characteristics of the ash. Such studies are desirable from the point of view of extending the fuel supply for a given plant to a wider range of fuels than that considered in the original design, with possible economies.

Similar studies, on a more empirical basis, have been reported by Reich[11] for the 12th Street Station of the Virginia Electric and Power Company. He operated successfully with a blend of coals containing 20 per cent of coals outside the contract specifications, which included refuse marketed as bone-coal, anthracite culm, local outcrop strippings, machine cuttings and mine dust. For the same excess air, he tapped continuously at 70 per cent full load with coal having a slag fluid temperature of 2500 F, and at 90 per cent full load when the slag fluid temperature was 2650 F.

It is hoped that the procedures outlined here will assist operating personnel in making such studies. The information required is: (1) the operating conditions with the basic plant coal, such as analysis of the ash of the coal; (2) analysis of tapped slag, including the state of oxidation of the iron, to determine the segregation effects in the furnace; (3) the temperatures of slagged walls and tapped slag; and (4) an estimate of heat absorption in the furnace with the basic coal. The slag temperatures may be obtained with reasonable accuracy by means of an optical pyrometer. From analyses of the ash of alternate fuels, the temperature of critical viscosity and the viscosity of the slag can be determined, and the range of ratings for the new fuels then can be estimated in terms of the experience with the standard coal. This method can best be illustrated with a hypothetical example.

EXAMPLE

Assume that a slag-tap furnace is fired with Illinois No. 6 coal having 12.9 per cent ash with the following analysis:

	As Analyzed, Per Cent	SO_3- and Alkali-free Basis, Per Cent
SiO_2	46.5	50.3
Al_2O_3	20.4	22.1
Fe_2O_3	19.8	21.4
$CaO + MgO$	5.7	6.2
SO_3 + alkalies by difference	7.6	

[11] "Utilizing Refuse Coals at 12th Street Station, Richmond, Virginia," J. A. Reich: COMBUSTION, vol. 12, April 1941, pp. 43–46.

The slag tapped has an iron oxide content of 33.1 per cent, expressed as total equivalent Fe_2O_3, and a ferric percentage of 20. Assuming that only the total iron oxides varied between the ash and slag, the SiO_2, Al_2O_3 and $(CaO + MgO)$ remaining in the same ratio, and neglecting the insignificant amount of SO_3 and alkalies in the slag, the analysis of the slag on the four-component [$SiO_2 + Al_2O_3 + Fe_2O_3 + (CaO + MgO) = 100$], or SO_3- and alkali-free basis, would be as follows:

	Per cent
SiO_2	42.8
Al_2O_3	18.8
Fe_2O_3	33.1
$CaO + MgO$	5.3

The percentage of silica, on the basis that $SiO_2 + Fe_2O_3 + (CaO + MgO) = 100$, would be

$$100 \times \frac{42.8}{42.8 + 33.1 + 5.3} = 52.7\%.$$

The viscosity of this slag at 2600 F is found directly from the scale at the right in Fig. 1 to be about 13 poises and to become 250 poises at about 2040 F. The temperature of critical viscosity, T_{cv}, may be estimated from Fig. 3, the silica:alumina ratio being close to 2.0, and is found to be 2200 F. Therefore, this slag could be tapped successfully at temperatures as low as 2350 F. The relative thickness of slag deposits, estimated from Fig. 6, would be 0.24; that is, it would be about one-quarter the thickness attained by slag having viscosity of 100 poises at 2600 F and T_{cv} of 2600 F.

For comparison, it is next assumed that instead of Illinois No. 6 coal the furnace is fired with Pocahontas No. 3 coal, which has considerably less iron. The ash is 6.8 per cent, with the following composition:

	As Analyzed, Per Cent	SO_3- and Alkali-Free Basis, Per Cent
SiO_2	49.8	53.5
Al_2O_3	24.6	26.4
Fe_2O_3	12.0	12.9
$CaO + MgO$	6.7	7.2

Because of the lower iron content of this ash, it may be expected that the ratio of iron oxide in the slag to that in the ash will be lower than in the previous example. Assuming the slag to have 15 per cent total equivalent Fe_2O_3 and neglecting the minor amounts of SO_3 and alkalis present, the slag analysis on the four-component basis [$SiO_2 + Al_2O_3 + Fe_2O_3 + (CaO + MgO) = 100$] will be:

	Per Cent
SiO_2	52.2
Al_2O_3	25.8
Fe_2O_3	15.0
$CaO + MgO$	7.0

The percentage of silica, on the basis that $SiO_2 + Fe_2O_3 + (CaO + MgO) = 100$, would be 70.3, and Fig. 1 shows that the slag would have a viscosity of 180 poises at 2600 F and 250 poises at 2550 F. The ferric percentage may be expected to be somewhat lower than that for Illinois coal under similar operating conditions, and for the present case is assumed to be 15. Linear interpolation from Fig. 3 shows $T_{cv} = 2450$ F. Therefore, by either criterion for optimum tapping, the lowest tapping temperature would be approximately 2550 F, preferably 2600 F, to obtain a lower viscosity. The relative thickness of slag deposits, interpolated from Fig. 6, would be 0.85.

It is seen, therefore, that, for a given furnace temperature, other conditions being the same, the Pocahontas coal would produce a thicker slag on the walls than the Illinois coal, thereby causing less furnace heat absorption and consequent higher exit-gas temperatures.

On the other hand, the greater insulating tendency of the Pocahontas coal would result in higher furnace temperatures for a given Btu input and tend to cause the slag coating to become thinner, thus counteracting the loss of heat absorption. The details of a method for correcting for this effect are given in reference 6.

This example, although extreme, nevertheless illus-

trates the method of approach to the problem. The greatest usefulness of the procedure for the time being may be to provide a rational method of analysis of the effect of fuel changes made in the regular course of plant operation. Accumulation of information through a systematic plant study by this method of examining the slag properties and ash behavior should soon provide a fund of knowledge on which to base coal selection and operating procedure.

An actual plant study of this type was reported by Luke[12] and was based only on the temperature-composition-viscosity relations shown in Fig. 1.

Further to illustrate the applicability of these procedures, the Bureau of Mines recently was asked for advice regarding the suitability of certain Netherlands coals for use in slag-tap furnaces. On the basis of analyses of the ash of seven coals in question, it was concluded that, to obtain suitable viscosity for continuous tapping, the temperature required would be excessive for five of the seven coals.

Nature of Tapped Slag

Slag tapped from continuous tapping furnaces and quenched occurs as needles, strings or fish hooks, which are difficult to handle and dispose of, or as granulated slag, which is more readily handled and has some commercial value. The decisive factor determining the nature of the tapped slag seems to be the inherent viscosity of the slag, that is, its viscosity at some standard temperature. It was found that the slags tapped from the primary furnaces of several slag-tap furnaces of an eastern utility were predominantly granular if the viscosity of the slag at 2600 F was less than 25 poises and predominantly stringy and needlelike if the viscosity of the slag at 2600 F was over 25 poises. In this particular plant, it was possible to regulate the coal supply so that the tapped slag would be uniformly granular. It is not suggested that a viscosity of 25 poises at 2600 F is a universal criterion for obtaining granular slag, but rather that the inherent viscosity determines the physical form of the quenched slag.

Control of the physical form of quenched slags can be achieved by the operator through a selection of coal. The first prerequisite is that, for a given furnace, complete data be available on the chemical analysis and the form of slag produced under normal operating conditions. Then, with the aid of Fig. 1, the viscosity at 2600 F can be correlated with form of the slag, and these data will establish the limits of η_{2600} required to obtain granular slag from the furnace in question. Thereafter, by means of the procedures followed for the Illinois and the Pocahontas coals, the behavior of any other coal can be determined from analysis of its ash.

There is little doubt that, in the examples cited previously, the slag from Illinois No. 6 coal would be granular and that from Pocahontas No. 3 stringy.

Return of Fly Ash to the Furnace

There has always been considerable interest in the return of fly ash to the hearth of slag-tap furnaces to decrease stack emission by increasing retention of ash in the furnace. Although the merits of this procedure depend upon each particular case, certain basic principles apply. The return of fly ash to the furnace will increase the accumulation of suspended fly ash in the furnace and increase the load on the cyclones or other ash-separating equipment. Furthermore, since the recirculated fly ash tends to be more refractory than the slag normally retained in the furnace, the minimum rating at which slag can be tapped will increase. An additional difficulty results when high-carbon fly ash is returned to the furnace, as the carbon acts to reduce the iron in the slag to metallic iron, possibly leading to the formation of salamanders. Tests have shown the reduction of carbon loss by recirculation of fly ash in pulverized-coal-fired boiler furnaces to be insignificant.

Deposits on Boiler and Superheater Tubes

The mechanism of adherence of ash to furnace, boiler, and generating tubes is not well understood. The metal temperature of such surfaces is far below that at which a plastic bond between the metal and the slag would be expected to occur. Nevertheless, it is easily observed during the operation of a furnace, starting with clean metal surfaces, that a deposit of fine ash occurs on the metal shortly after the coal feed is started. As this initial layer of ash provides a base to which coarser ash constituents can adhere and ultimately increase in thickness until slagging occurs, prevention of its formation might conceivably insure clean metal surfaces. However, since no feasible means to do this are available at present, some control over slagging of screen, boiler and superheater tubes is obtained by close attention to the furnace exit-gas temperature. The maximum permissible exit-gas temperature is not known exactly, being a function of the properties of the ash present where slagging is likely to occur. However, Bailey and Ely[9] recommend that the gas temperature not exceed the A.S.T.M. initial deformation temperature, determined under oxidizing conditions, of the ash in the "as-fired" coal.

Conclusion

Better understanding of the effect of ash and slag on furnace performance has suffered from lack of practical plant tests. To some extent this has been due to the assumption that ash is an inevitable nuisance in power plants. It is possible that new developments in the design of pulverized-coal-fired steam generators will proceed no faster than fundamental and engineering studies of the behavior of ash and slag accumulate. Similarly, progress in coal-fired, gas-turbine technology may depend largely on such studies.

The problem is amenable to solution. First, there is needed extended correlation of the behavior of ash and slag in furnaces and boilers with the chemical, mineralogical and flow properties of ash and slag. The preliminary step in this direction would be to make complete chemical, petrographic and X-ray diffraction analyses of ash samples from various parts of a large number of boilers and correlate these data with the physical properties of the samples. Second, a complete laboratory investigation should be made of the mineralogical changes in a wide variety of coal ashes when they are heated to various temperatures. Third, the mechanism of adherence of ash to metal surfaces should be studied under the operating conditions of boiler and superheater surfaces.

It is only through a research program of this scope that the behavior of ash in furnaces will be rationalized.

[12] "Coal Characteristics Determine Furnace Performance," Allen W. Luke, Jr.: *Power Plant Engineering*, vol. 44, Nov. 1940, pp. 44–48.

Instruments and Combustion Control for Small Plants*

This discussion is directed toward steam plants in the range of approximately 3,000 to 20,000 lb of steam per hour output or consuming between 1,000 and 8,000 tons of coal per year. Benefits of instruments and combustion control are reviewed as as well as their possible arrangement to fit the individual plant requirements.

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IN THE small size of power plant, instruments and automatic combustion control are usually given disproportionately less consideration than the boiler, fuel burning equipment, pumps, and other necessary equipment as compared with larger steam generating stations. This is probably due to several reasons, the most important of which are:

1. The small plant can produce steam without instruments and control while in the larger more complex installations some automatic or at least remote manual control is necessary.

2. There is no question of the economic value of an elaborate installation of instruments, safety control, signal devices and automatic combustion control for the larger units, while on the smaller units the margin of return on the investment is closer.

3. Management, designing and operating engineers dealing with the larger steam generating units have become better informed on the subject of instruments and controls, while the installation of a small steam generating plant many times is only one small portion of a large expansion to a manufacturing plant or institution, the rest of which demands the major portion of the time and consideration of all concerned. As a result, the instruments and automatic combustion control are often considered an unimportant part of the steam generator and are not given the deserved attention.

Draft Gages

Since most steam generators in this class are simple in design, usually a three-pointer draft gage is ample. An indication of the furnace draft is the most important and next is the pressure of the air for combustion. When multiple-zone stokers are used air pressure under each zone should be indicated so that the operator will be properly guided in distribution of air to the fuel on the grates. Last in importance is draft ahead of the boiler outlet damper or after the gases have passed the last boiler heating surface. All these indications are helpful to the fireman in properly controlling the air for combustion and its distribution to the fuel.

Steam-Flow Meters

Steam-flow meters have been called the cash register of the boiler room. They tell how efficient the fireman has been in spending fuel money. Steam meters which record and integrate the flow of steam from the boilers give an accounting of the steam produced with the fuel. The chart shows the changes in load as they occur throughout the 24 hr. By observing the chart the operator is informed of the load trend and can prepare to handle the load most economically by cutting boilers into or out of service and adjusting the fuel bed conditions. It is good engineering practice to provide each steam generator with a steam-flow meter.

The integrator totalizes the amount of steam generated during a given period and, together with the amount of fuel burned for that purpose, establishes the cost of fuel per 1000 lb of steam generated and used. The efficiency with which the steam was generated can also be determined, and is generally expressed as a relationship of pounds of water evaporated per unit of fuel burned.

Feedwater Meters

Feedwater meters have in general given way in favor of steam-flow meters where a choice has to be made between them. The steam-flow meter gives a better indication of the load since it actually follows the rate of steam generation. The feedwater flow does not always equal the rate of steam generation and therefore the meter does not indicate the actual load condition. In large plants feedwater meters are used as well as steam meters.

Positive-displacement hot-water meters have been used to measure feedwater on small-sized steam generating units where it was believed the cost of the recording and integrating type of flowmeter was not justified. However, since hot water has practically no lubricating qualities, frequent repairs and recalibration of this type of meter is required.

Combustion Guides

There are three combustion guides available: The orsat for manual analysis of the flue gases, the automatic carbon-dioxide recorder and the air-flow to steam-flow relationship.

The orsat is primarily a test instrument for use when a boiler or combustion test is being run, for checking the calibration of automatic CO_2 recorders, or the calibration of air-flow relationship to the steam flow on boiler efficiency meters. It is also used to calibrate automatic combustion control systems when one of the two latter-

*Excerpts from a talk at the joint A.I.M.E.-A.S.M.E. Fuels Meeting, Cincinnati, O., October 20 and 21, 1947.

mentioned combustion guides are not available. It is not intended as a daily operating guide for the fireman.

The automatic carbon-dioxide meter is used extensively in this size plant and its readings are used as a direct guide for adjusting the fuel-air ratio for combustion efficiency. With the CO_2 and flue gas temperature readings, the heat loss and therefore the fuel loss can readily be determined. It is good engineering to equip each steam generator with a separate CO_2 instrument. However, it is possible to connect one CO_2 meter to several steam generators but preferably not more than three. Two CO_2 instruments are sometimes used with three steam generators.

Relationship between air flow and steam flow can be obtained by combining an air-flow record with the record of steam flow on the steam-flow meter chart. This guide for combustion efficiency must be individual to each steam generator since it is combined with the steam-flow meter for that generator. This is also made necessary by the fact that the air-flow record is individually calibrated to the steam generator with which it is used. As a result, it cannot be used when only one steam-flow meter is employed to measure the steam output of several boilers.

Other Instruments

In addition to draft gages, steam meters and combustion meters, indicating and preferably recording instruments should be provided for steam pressure in the main header, temperature and pressure of the feedwater, and temperature of the flue gases at the outlet of each steam generator. Records of these functions can generally be incorporated on the chart of the steam-flow meter and CO_2 meter or several such records can be combined into one instrument. Not only does this reduce the cost but it also coordinates the several records of related functions on the same chart.

Automatic Combustion Control

Automatic combustion control is purchased for what it will do and do better than can be done in any other way. Primarily, its purpose is to increase the efficiency of combustion and save fuel dollars. Too often, however, this is the only credit given to automatic control.

Labor saving is no doubt next to fuel saving as one of the benefits. In most plants it is not expected to replace completely any of the operating personnel with automatic control, but what it does do is relieve the firemen from the tedious task of adjusting the fuel control, forced-draft, and boiler-outlet dampers in an effort to hold the steam pressure and furnace draft constant while keeping efficiency up to within shooting distance of test efficiencies. It allows the operators to use their time to the far greater benefit of observing and correcting overall operating conditions and thereby maintain improved efficiency.

On the basis of fuel and labor savings and the greater return on the investment alone, it is likely that more and better automatic combustion controls will be installed in this size plant in the future.

Safety is another factor in the operation of a steam generator which is improved through automatic control. Keeping the steam pressure within close limits and holding the furnace draft at a constant value and preventing a positive pressure in the furnace are two of the safety benefits of automatic control. Flame-out controls when firing oil and gaseous fuels may also be added as safety features. Load-limiting controls to keep the rate of steam generation within the capacity of fans or prevent the feed of fuel without the air to burn it are other features which can also be incorporated to improve safety.

It is safer to operate a steam generator to more nearly its maximum capacity under automatic control than manual control. This may at times eliminate the necessity of putting additional units into operation to meet short peak load conditions which is the same as saying that the steaming capacity of the unit is increased through the use of automatic control.

Automatic Combustion Control Systems

Automatic combustion control systems are of two general types, positioning and metering. Both systems operate on the same general basis. They both respond to changes in steam pressure as being representative of changes in demand for heat input to the steam generator. They both control the rate of flow of fuel and air for combustion in an effort to maintain the steam pressure within close limits and efficiency of combustion at a high level. They both use a furnace draft controller as part of the control system, one for each boiler, to hold the furnace draft constant at a predetermined low negative value, generally by operating the boiler outlet damper. The two systems differ in the method used to control the rate of fuel and air for combustion.

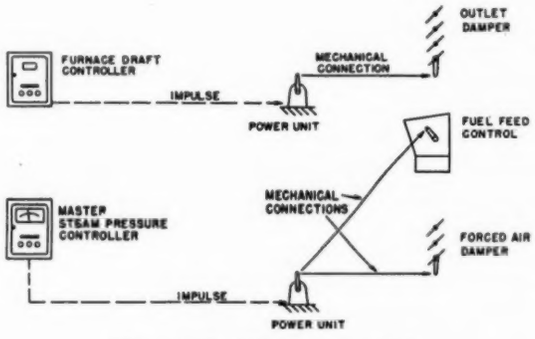


Fig. 1—Positioning control

The positioning system, outlined in Fig. 1, consists of one master steam pressure controller which adjusts the rates of fuel and air flow directly by positioning the lever that controls the rate of fuel, the flow of fuel and the damper that controls the flow of forced draft air into the combustion chamber. Only one master controller should be used to control all of the steam generators connected to the same steam header in which the pressure is being controlled. It may appear logical and desirable to equip each steam generator with a master controller, thereby eliminating shafting and linkage or other means of transmitting the master loading impulse to all boilers. Such an arrangement is satisfactory except when more than one boiler unit is in operation at any one time. The result when more than one steam generating unit is in operation at any one time is to swap the load between boilers. In other words, one or more of the boilers picks up most of the load while the rest of the boilers drop it and then the reverse cycle takes place. The use of one master steam pressure controller eliminates this action.

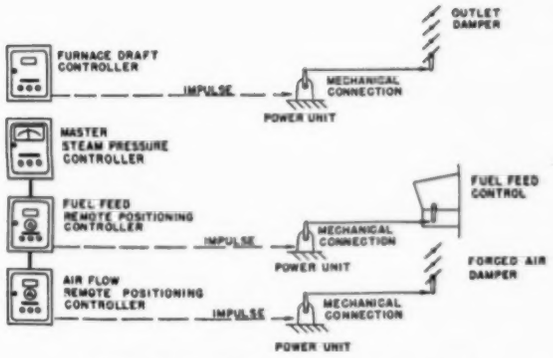


Fig. 2—Remote positioning control

The one master steam pressure controller can be connected through mechanical linkages such as chain or cable and sheaves or shafting, levers and linkages to the air and fuel controls on all the steam generating units. This system is clumsy, is expensive to install and maintain with too much lost motion, and provides no flexibility of operation in the way of means for changing fuel-air ratio or the loading of boilers. Too great a percentage of the total cost is in the installation which does not enhance the quality of the controlled results.

A system which is much preferred is one in which the mechanical connections are reduced to a minimum or to that required between the individual power unit and the damper lever or fuel control which it operates. This is sometimes referred to as a remote positioning control system (see Fig. 2). The master loading impulse is transmitted electrically, pneumatically or hydraulically to these individual power units quickly, accurately and without lost motion. With this system manual control and adjustments can easily be provided at a centrally located panel on which the instruments are mounted or on individual panels at each steam generator.

By means of the manual control stations flexibility of operation is obtained. Steam generators may be taken off automatic control and placed on base load or fixed output, ratio of fuel to air may be changed at will, and any one or all functions of the steam generating unit may be automatically or manually controlled from the panel as desired by the operator. These are very important features since a positioning system does not always make exactly the required change in the air and fuel supply for each change in load. Therefore a manual adjustment must be made to compensate for any error in order to obtain maximum efficiency of combustion.

The errors referred to are due to two factors. First, is the fact that the character of the relation between the rate of fuel feed and the position of the lever controlling it is not a straight line. Also the character of the relation between the rate of air flow and the position of the forced-air damper likewise is not a straight line. In addition, both relations are never exactly alike. It is therefore practically impossible to calibrate accurately the simultaneous movement of the fuel and air control levers to produce the desired air-fuel ratio over the entire range of operation. However, through the adjustment of lever lengths and the relative angular travel of these levers, very satisfactory control can be obtained.

The second factor that is also a source of error in the positioning type control is the variable conditions which affect the results which would otherwise be secured by the mechanical calibration of the linkage system. For example, any one position of the fuel feed control lever may not always cause the corresponding rate of fuel to be fed into the furnace. It will be changed by variations in valves, pumps, motors, turbines, engines, viscosity of fuel oil, pressure of gas, steam pressure, load on the stoker drive, and slippage of drive belts, or lost motion in the feeding mechanism, etc.

Any one position of the forced-draft air damper may not always cause a corresponding rate of air flow into the furnace due to the variations in fuel-bed resistance, atmospheric conditions, boiler settings, fans, motor or turbine drives, zone damper positions and lost motion in damper linkage. When one fan supplies air to more than one boiler, the number of boilers, their load and location in relation to the fan affect the air volume to each boiler. It is not feasible to control fan speed for air volume with a positioning system of control.

Despite these possible sources of error the positioning system will do a good job of controlling steam pressure and furnace draft, and, since with a good mechanical calibration of the system and the fact that the variables listed above which might affect it sometimes cancel each other, fairly good control of fuel-air ratio can be obtained with an occasional manual adjustment. *It must be remembered, however, that a control system will control for high, fair or poor efficiency depending upon adjustment.*

A better answer to the control problem which compensates for most of the variables mentioned and can be more easily and accurately calibrated to a high percentage of efficiency and maintain it with fewer manual adjustments required, is the metering system of control, Fig. 3. It is based on the principle of measurement and controls the fuel-air ratio according to pre-determined measurement. This type of automatic control has not as yet been extensively used in the size of plants under consideration, but is now being used almost exclusively in slightly larger plants.

This system of control differs from the positioning system in that in addition to one master steam-pressure controller and a furnace-draft controller for each steam generator, a separate air and a separate fuel feed controller are provided for each boiler which controls the fuel-air ratio on a measured basis. In addition to having all of the flexibility of the remote positioning control system, it has the added advantage of not requiring calibration of the mechanical linkage used. Also it compensates for practically all of the variables which affect the positioning system of control.

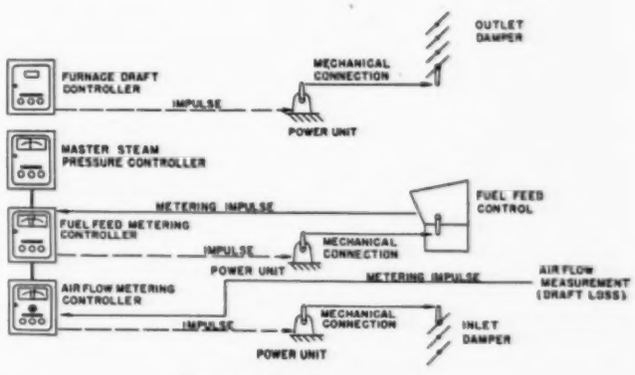


Fig. 3—Metering control

Notes on Radiology of Welded Pipe Joints

IN A PAPER by E. Thomas before The Institution of Mechanical Engineers (Great Britain) the author discusses both shop and field examinations of welded pipe joints, and gives some practical suggestions on procedure in making an examination. These suggestions are, in part, as follows:

"More attention should be paid to the positioning of welds in piping systems by designers, even though it may entail more joints. If possible, when joints are located under solid floors, they should be placed under holes in the floor or a reasonable amount of headroom should be allowed.

"In the examination of small pipes up to about 4 in. diameter the method usually adopted is that of oblique projection (Fig. 1), the source being positioned at a suitable distance from the weld so

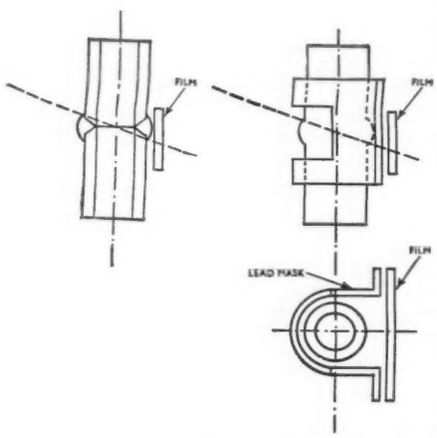


Fig. 1—Examination of small pipes

that the radiation penetrates the plane of the weld at a small angle. The film is contained in a rigid, flat cassette and the resulting radiograph will indicate the weld as an ellipse. The source-film distance should be such that the two sections of the weld are observed on the same film. The thicker the pipe wall, the shorter will be the useful length of the film.

"Unless great care is taken, the results will be disappointing, and particular attention should be paid to the masking of the pipe to prevent scatter from reducing the effective area of the resulting film. Sheet lead is probably the best material to use for this purpose. The opening should be a little less than half the circumference of the weld and the lead very closely pressed to the surface of the pipe.

"The method of examining large pipes when one tube wall only is penetrated depends upon the pipe size and that of the shield containing the source. The method in which the shield is small enough to be placed inside the pipe with the film arranged outside the pipe, as in Fig. 2a, is seldom realized owing to difficulty of maintaining the source in position. Special X-ray tubes are available for examining cylinder bores that have the source at the end of the shield. This is a case where gamma rays offer advantages over X-rays since, with the source removed from the shield and accurately located at the center of the pipe, it is possible to expose a series of films around the pipe and, with care, one exposure may suffice for the whole joint.

"Providing the site conditions are suitable, the better method is to have the source arranged externally with the film inside the pipe, as in Fig. 2b, as the more serious faults usually lie at or near the root of the weld and, being nearer to the film, they will be more readily detected.

"Where it is impossible to place the film inside the pipe, recourse must be had to the method in which the source is placed externally to the pipe with the film on the opposite side and both tube walls will be penetrated, as indicated in Fig. 2c. Here the side of the pipe nearest to the source acts to some extent as a filter and generally its image will be diffused. However, if the image does affect the film, it will be necessary to take an oblique shot. The X-ray tube can be brought right up to the pipe and thus permit a minimum exposure time.

Double-Exposure Technique

"Most faults that are of a magnitude sufficiently large to require an investigation into their position may be readily located by means of the double-exposure technique shown in Fig. 3. Here the film is securely fixed in position, and with the source at position *A*, an exposure is made, followed by one at position *B*, the film remaining in its original position. Two images of the fault will be found on the film and from them an estimate of its position may be quickly made either by calculation or by drawing. By these methods it has been possible to show that base cracks existed and to separate out several pores in arc-welded material.

"It is also possible to determine the position of faults by using overlapping films, providing there is some means of locating some fixed points on the films; a simple method being to work from position markers applied to definite positions on the pipe circumference.

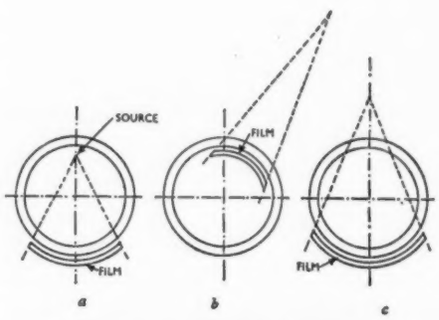


Fig. 2—Examination of large pipes

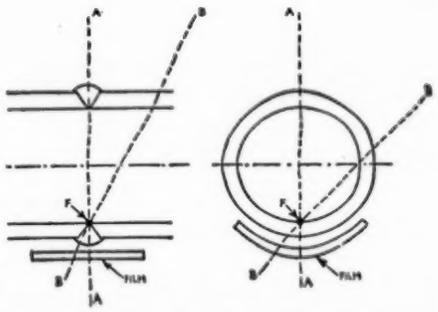


Fig. 3—Localization of faults by double exposure

"With gamma-ray examination of steel pipe the film grain size plays a much more important part than in the case of X-rays. Experience has shown that slow-speed, fine-grain film used with metal screens is necessary for the results of gamma-ray examination to approach the results obtainable with X-rays using fast salt-screen type film and two salt screens."

New High Mark for Fuel Production

Despite a $1^1/_4$-hr reduction in the working day during the second half of the year, the 1947 output of bituminous coal in this country exceeded 617 million tons which represented a new peacetime record, amounting to 17 per cent over that of 1946. In addition more than 57 million tons of anthracite were produced, a decline of 6 per cent from that of 1946. This overall achievement, responding to a greatly increased demand, was brought about by closer cooperation between miners and operators, improvement in mining methods through a high degree of mechanization, and the fact that there were fewer and shorter strikes in the industry. As a matter of fact, only 19 million tons of production were lost in 1947 because of strikes, compared with 107 million tons in 1946.

Production of crude petroleum, according to the U. S. Bureau of Mines, reached 1855 million barrels—an increase of 7 per cent over 1946 and a new record. However, the oil sales (domestic and export) exceeded 1946 by more than 10 per cent, the difference being made up through a decrease in stocks and an increase in imports. Inasmuch as the total export of all grades of oil amounted to only 164 million barrels in 1947, compared with 151 million barrels in 1946, it is apparent that the major increase in demand was domestic.

The marketed output of natural gas in 1947 increased nearly 10 per cent over the 1946 total and reached a new record of 4400 billion cubic feet, valued at points of consumption of over a billion dollars.

The total value of the 1947 output of mineral fuels (coal, oil and gas) is estimated at approximately $7,800,000,000, compared with $5,725,000,000 in 1946, an increase of 36 per cent. The average value per net ton of bituminous coal at the mine was $4 in 1947, compared with $3.44 in 1946.

Electrical Output for Year Sets New Record

AS THIS issue goes to press the exact final figures as to the total 1947 energy production by electric utilities (privately and publicly owned) are not available, but a report issued by the Federal Power Commission on December 26 permits a close approximation to be made. This gives the output for the twelve months ending November 30, 1947, as slightly over 253 billion kilowatt-hours, which exceeded that of the preceding twelve months by 14.8 per cent. Adjusting for the 1947 monthly increases over those of 1946, would indicate the total 1947 output to have been more than 256 billion kilowatt-hours—a new record exceeding the highest of the war years (1944) and above the last pre-war year (1940) by 80 per cent.

During these seven years generating capacity increased from 40,033,000 kw to approximately 52,000,000 kw, or about 29 per cent. The same report gives stationary industrial power capacity as 12,822,465 kw at the end of November 1947.

EEI Estimates

Another source, the Edison Electric Institute, estimates total output of electricity from all sources as about 305 billion kilowatt-hours of which private utilities are credited with 204 billion, publicly owned systems 50 billion and industrial plants, including street railway plants, 51 billion. Thus the combined private and publicly owned utilities account for 254 billion kilowatt-hours which is somewhat less than the Federal Power Commission figures would indicate.

During the year just passed there was a marked increase in residential consumption of electricity. This reached an annual average of 1435 kwhr per customer which was 106 kwhr over that of 1946 and established a new all-time national average. According to the EEI new consumption records were set by all major classes of consumers, except industrial.

Of the 65 million kilowatts installed in stationary power plants at the end of 1947, approximately 42 million kilowatts was in private utility plants, 10 million kilowatts in federal and municipal plants and nearly 13 million kilowatts in industrial plants which generate their own power.

Approximately 2 million kilowatts of additional capacity was placed in service by the private utilities during 1947, which was about half the growth in demand. However, toward the end of the year new capacity was being added at a rate nearly in line with the load increase, and the 1948 expected additions will be over 5 million kilowatts which will exceed the anticipated increase in demand and thus make for a greater margin of reserve, up to about 8 per cent average. Construction expenditures by the private utilities during the coming year are expected to pass $1^3/_4$ billion dollars, and some 6 billion by the end of 1951 at which time 15 million kilowatts capacity will have been added. In other words, during the next four years capacity will be increased about 35 per cent. This is exclusive of over 2 million kilowatts of projected construction among public power plants, the greater part of which will be hydro in contrast to practically all steam-generated power by the private utilities.

Acid Cleaning of Boilers

Conclusions arrived at in a paper on "Experiences with Frequent Acid Cleaning of Steam Boilers," by S. K. Adkins before the Eighth Annual Water Conference, were in substance as follows:

1. In no case should a temperature higher than 150 F be employed; and, if conditions permit, lower temperatures are desirable. If possible, the boiler should be cooled well below the temperature at which the cleaning will be conducted and, if necessary, warmed with hot water to the minimum necessary temperature before cleaning. This will tend to eliminate hot spots.

2. The shortest possible period compatible with satisfactory cleaning should be employed. Since the type and characteristics of deposit largely determine the time of contact, it is desirable to determine in the laboratory the time required to disintegrate the deposit.

3. The lowest possible concentration of acid that will accomplish the desired results should be used up to 5 per cent maximum. It is also possible to start with a low concentration, add acid during the soaking or circulation period, and maintain acid strength sufficient to complete the cleaning of the surfaces within a reasonable time.

4. Selection of the best inhibitor and the optimum concentration thereof is largely a laboratory program. As a result of investigations, it was found that the concentration that afforded the best protection with a 3 per cent acid strength was 0.5 per cent by volume. Increased concentration above this appeared to have little additional effect.

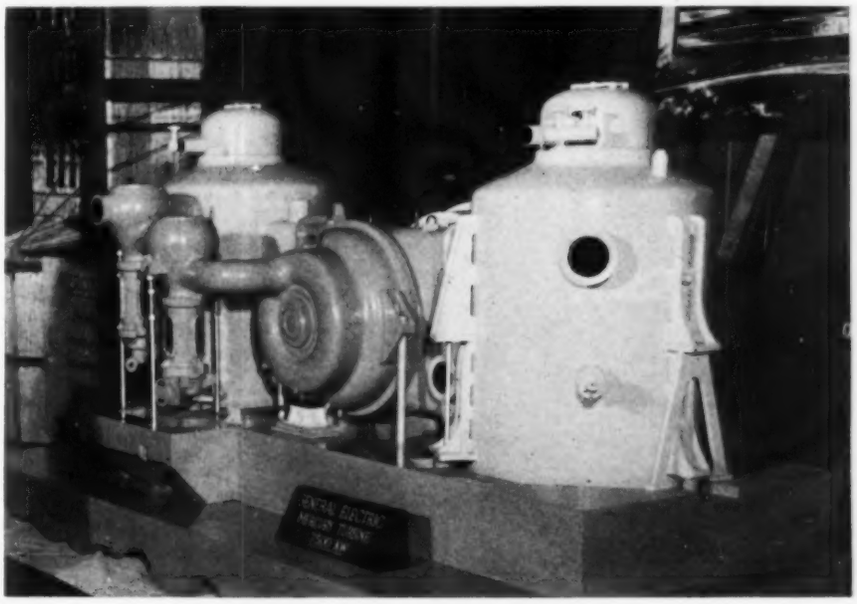
5. The greatest problem is to obtain thorough contact of all acid-exposed surfaces with the neutralizing solution.

6. If all the factors of temperature, time, solvent concentration and rinsing are properly considered, the effect of repeated acid cleanings should be nearly negligible; but experience has shown that once corrosion has been allowed to progress, its rate will increase.

7. Most power plant personnel fear acid, but are prone to ignore dangers attendant upon its use for cleaning boilers. The chemist can do much, through explanation of the hazards, to minimize the danger.

New Hampshire Company to Install Mercury Unit

The illustration represents a scale model of a new type G. E. mercury turbine, two of which are to be installed by the Public Service Company of New Hampshire at its Portsmouth Station. Each unit consists of a mercury boiler, a 7500-kw, 1200-rpm turbine-generator and a condenser-boiler for the production of steam. The output of each condenser-boiler will pass through a superheater located in the combustion space of the mercury boiler. The steam flows are then combined at 600 psi, 825 F to feed a 25,000-kw, 3600-rpm steam turbine direct-connected to a hydrogen-cooled generator.



New type G.-E. mercury turbine and boiler unit.

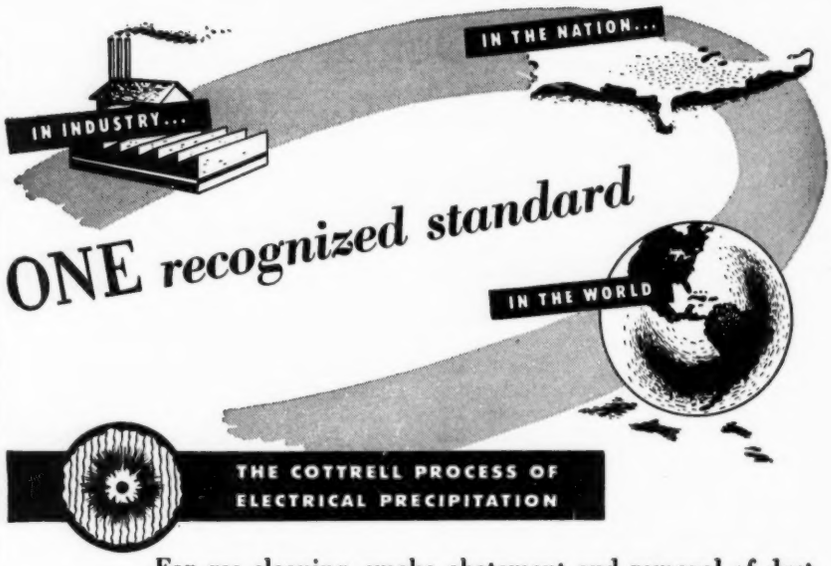
Some New Turbine-Generators

In its annual statement the General Electric Company mentions that three 1000-F turbine-generator units were delivered during the past year and that six others are under construction. Also, being built are six units, totalling 700,000 kw, which will operate with steam at 1050 F.

Among the most significant turbines under construction are three 125,000-kw, 2000-psig, 1050-F units for the new Philip Sporn Station of the Appalachian Electric Power Company and the Twin Branch Station of the Indiana & Michigan Electric Company. A 150,000-kw tandem-compound turbine for Fiske Station in Chicago will operate at 1250 psig, 925 F and a unit of like capacity and similar design, but to operate at 950 F, is being built for the Richmond Station in Philadelphia.

An unusual turbine reported by Westinghouse is a 65,000-kw, 1450-psig, 1000-F triple-cylinder machine building for the Edgar Station of the Boston Edison Company. Steam will be exhausted from the high-pressure cylinder at 365 psig and then returned to the boiler for reheating to 1000 F before passing to the intermediate-pressure cylinder.

Among industrial turbines, a 30,000-kw back-pressure, extraction machine for the Dow Chemical Company employs an unusual and most complicated automatic hydraulic extraction system. The unit is designed to operate at 1250 psig, 825 F, with extraction at 425 psig and 165 psig. Exhaust is at 25 psi.



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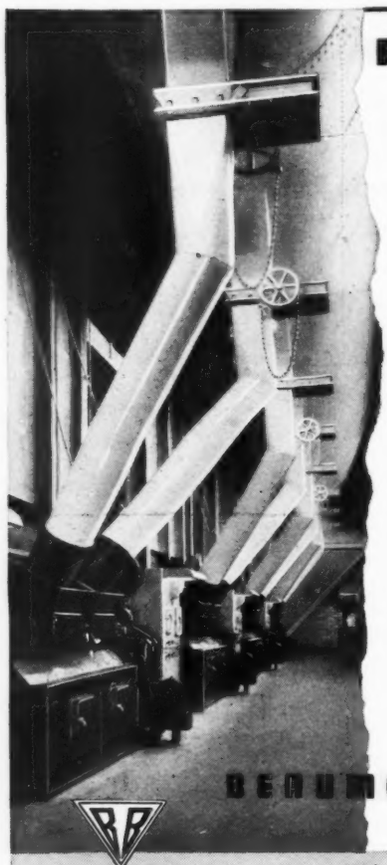

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Brazilian Company Formed

Combustion Engineering Company, Inc., New York, has announced the formation of Combustion Engineering Limitada, with headquarters in Rio de Janeiro, Brazil. The new company will take over the offices and most of the personnel of Sociedade Termotecnica Mellor-Goodwin, Ltda., which organization formerly served as the Company's Brazilian agents.

William H. Billich will be the resident manager of the new firm. Mr. Billich for some years past has been in charge of Combustion Engineering's Washington, D. C., offices and has also been closely associated with the Company's work in the export field. Prior to this, he spent 17 years with a large consulting engineering firm.

Formation of the new company has been undertaken in order to provide an organization adequately staffed to serve the increasing power needs of Brazilian industry. Combustion Engineering has been supplying boilers and fuel burning equipment to Brazilian plants for many years past and has made many of the installations associated with the Brazilian industrialization program. Especially notable installations of recent years are those at the Volta Redonda steel mill and the Tubarao coal washing plant of Companhia Siderugica Nacional, the largest steel mill in South America; Companhia Nacional de Cimento Portland at Guaxindiba, the largest cement plant in Brazil; and Industrias Klabin do Parna at Monto Alegre, the largest pulp and paper mill.

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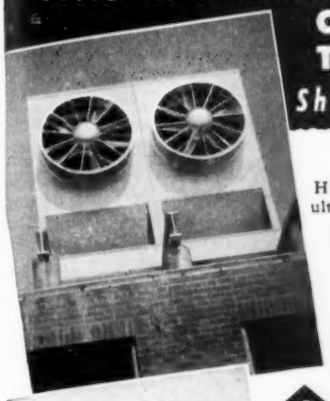

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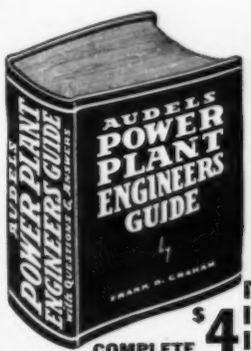
Ultrasonics Applied to Superheated Steam

A paper by **James Woodburn,** associate professor, Rice Institute, entitled "An Experimental Determination of the Velocity of Sound in Superheated Steam by Ultrasonics" was presented at the A.S.M.E. Annual Meeting. The author intended in this paper to acquaint engineers with this particular application of ultrasonic sound waves, and to present for the first time actual measurements of the velocity of sound in superheated steam. Of particular interest to designers and operators of steam power equipment should be the prospect of accurately determining steam purity, since it is proved that any trace of impurity in a gas materially alters the velocity of sound through it.

The term "ultrasonic" is used to describe sound waves which are higher in frequency than 20,000 cycles per second which is about the upper limit of detection by the human ear. The range of frequencies ordinarily used in ultrasonic work is from 50,000 to 3,000,000 cycles per second. The crystal used in these tests had a natural frequency of 575,000 cycles per second at room temperature.

The acoustic interferometer was the instrument used in these tests to measure the length of a standing sound wave. It consists of a quartz crystal which is made to vibrate electrically at its natural frequency to set up a series of standing waves within a vertical cylinder filled with steam, the lower end of which is closed with a movable piston. When the piston is moved to a position such that the distance between the piston and the quartz crystal is an integral number of half wave lengths, a sharp peak is produced in the voltage across the crystal. These peaks were detected by means of a vacuum tube voltmeter and galvanometer arrangement. Due to the length of a half-wave length interval, only a few thousandths of an inch, it was necessary to make very careful measurements and compensate for expansion of components of the interferometer.

Since the frequency of sound could be measured with an accuracy of one part in 200,000 and the length of the sound wave to half a thousandth of an inch, the actual velocity of sound was then calculated with high accuracy. This can be done while using small quantities of gas or steam.



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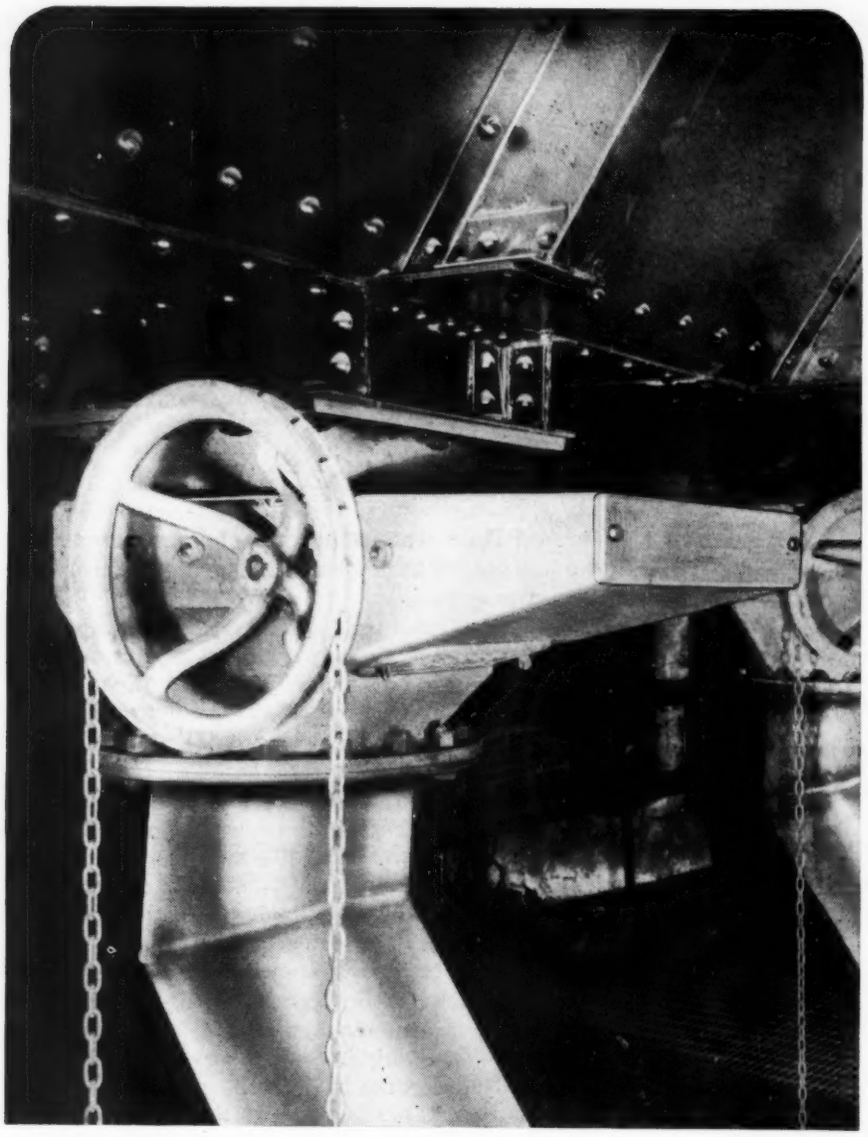

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NEW CATALOGS AND BULLETINS

Ejectors

"Steam Jet Ejectors" is the title of a new 36-page catalog, No. 1462, recently issued by the C. H. Wheeler Mfg. Co. In it are described the ejector operating principle and characteristics as well as single and multi-stage tube jets. Noncondensing and condensing types, with barometric inter- and after-condensers for vacuum requirements are fully covered. Also included is information on steam jet vacuum refrigeration for water-cooling requirements of air conditioning and process applications. The catalog contains many sectional drawings of equipment as well as flow diagrams, engineering data, installation guide, formulas, curves and tables.

Flexible Couplings

Poole Foundry & Machine Co., Baltimore, Md., has available Catalog 44 entitled "Flexible Couplings." This nicely bound 124-page booklet contains many installation views, descriptions of various types, together with dimensions for different types and size motors, plus installation and lubrication instructions.

Heat Recovery

Cochrane Corp. has released a new 16-page publication, No. 4410, describing five different flash-tank and heat-exchanger systems for recovering heat in boiler blowoff water. Included are: maintenance of boiler concentrations, the purpose of continuous blowoff which works some problems on heat recovery, and a chart for simplified savings estimate. Also included are illustrations of different classes of Cochrane continuous blowoff systems and their applications.

Micromax Instruments

Leeds & Northrup Co. has released catalog No. 44 (2) which includes, for the first time, all Round-Chart Micromax instruments under one cover. Included in this 16-page catalog are complete specifications in easy-to-use tabular form for automatic indicating recorders, and indicating and recording controllers. Suggested chart numbers are also listed for the more commonly used ranges, together with other accessories and supplies.

Insulation

"Heat Insulation for Industry" is the title of a 16-page bulletin issued by Philip Carey Mfg. Co. Included in its pages are a selection guide for industrial insulation, condensed specifications, a description of the various types of ma-

terials, as well as cements and weatherproofing. Also given is a selection chart for determining the thickness of insulation.

Oil and Gas Burners

Peabody Engineering Corp. has issued 4-page condensed bulletins, No. 803 and No. 903, which describe their Type M and Type ML industrial burners for oil and combinations of oil and gas. The bulletins discuss the operation of the burners and show installation views.

Steam Purifiers

A new edition of its 12-page bulletin describing steam purification units for the removal of moisture and solids in steam lines has been announced by Cochrane Corp. Included are installation views, hook-up diagrams, discussion of benefits derived from use of the purifiers, as well as accessory descriptions.

Steam Turbines

General Electric Co. describes in a 4-page bulletin entitled "Electrically Governed Steam Turbine" their Type DE turbine equipped with a means of obtaining accurate speed control. Included are brief descriptions together with illustrations of the speed-sensitive element, control panel and relaying mechanism. A schematic diagram of the governing system is shown also.

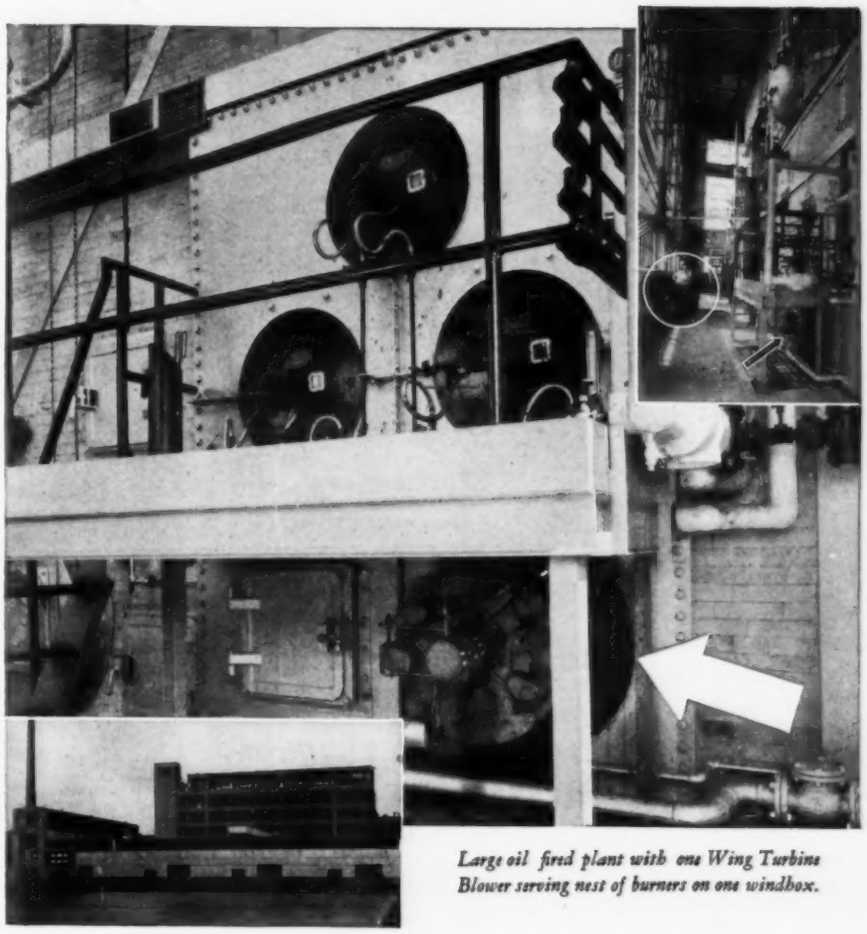
The Whiton Machine Co. has released an 8-page booklet on their solid-rotor-type steam turbine. The special features of this turbine are described and illustrated by cut-away and phantom views. Also included are a drawing and chart showing the principal dimensions for different sized machines.

Valves

Edward Valves, Inc., has issued a new catalog section (12-G6) describing forged-steel chrome-molybdenum "Intex" and "Univalves." Univalves are welded bonnet integral seat valves for service at 1500 and 2500 psi at 1000 F. Intex valves are bolted bonnet integral seat valves rated at 1500 lb and 1000 F. The bulletin gives details of construction, dimensional and design data, material specifications and other data.

Water Columns and Gages

Yarnall-Waring Co. has just issued Yarway Bulletin WG-1811, their latest edition on water columns and gages. This 20-page bulletin includes the following: description of the operation of the hi-lo alarm; construction details of water columns, try cocks and water level gages; details on flat glass inserts; column and gage arrangements for pressures above 400 psi; equipment for floor level readings of boiler water level; dimensions and prices; spare or repair parts list; and typical installation views.



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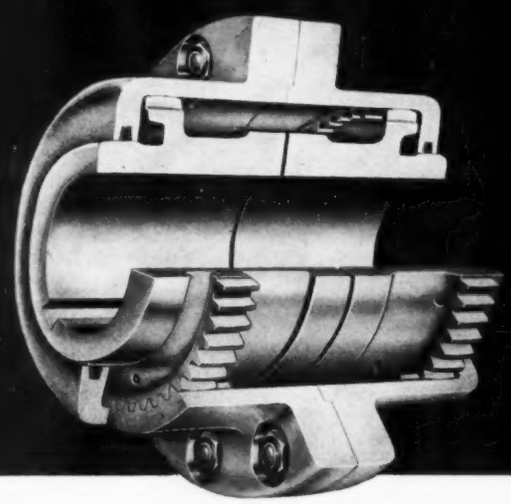

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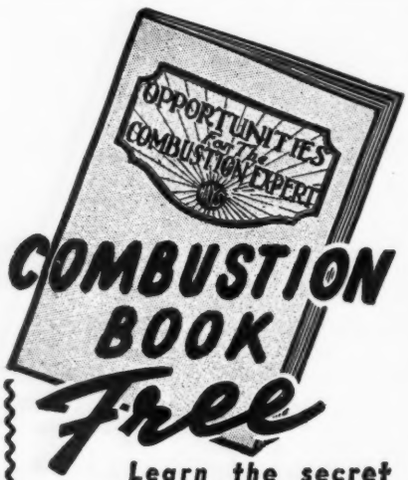

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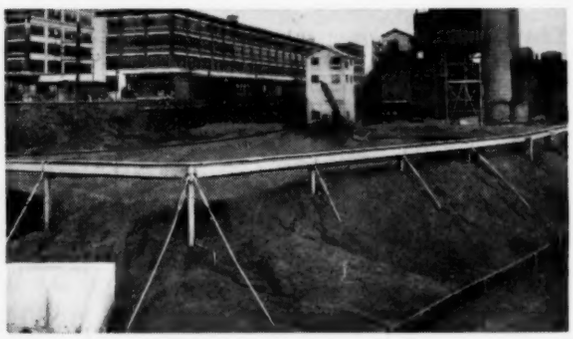

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